INSPECTION and GAGING

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A training manual and reference work that discusses the place of inspection in industry; describes the types of automatic and manual gaging and measuring devices employed; shows the proper techniques of using inspection equipment; and outlines the various duties of inspection personnel.

CLIFFORD W. KENNEDY

Late Quality Control Engineer, Federal Products Corporation
Providence 1, R. I.
formerly Chief Inspector, Remington Arms Co.
Denver Ordnance Plant

DONALD E. ANDREWS

Manager of Inspection, Federal Products Corporation
Providence 1, R. I.

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Preface

This book, or the idea of writing it, was war born. During the critical and hectic period from Pearl Harbor on, industry strained every fibre to supply war material fast enough. From the most minute instrument parts to the massive pieces of completed ordnance, this vast array of manufactured product had to be inspected and re-inspected throughout its various stages of production. Most of the inspection burden fell on the manufacturers and contractors.

Thousands of workers of both sexes were hired and assigned to inspection duties. Practically none of this horde knew anything about inspection methods and techniques. They came, most of them, from other fields of endeavor — housewives, store clerks, insurance salesmen; too few had had factory experience of any sort and those who knew anything at all about a machine, a bench, or even a wrench were diverted hurriedly to the hungry maw of production.

Many weary hours were spent by the few who possessed some industrial inspection experience, in teaching, demonstrating, and coaching. Many of us would have given the proverbial shirt, could he have presented the neophyte with a book explaining at least the elementary principles of inspection operations, to expedite the process of learning.

Today, new people are continually being inducted into industrial inspection departments in a new push to build up the sinews of defense. Even those who are not so completely uninitiated in manufacturing processes and machining methods, usually have only a vague or erroneous conception of the equipment and techniques of inspection and gaging. Then, it is not difficult to observe that in many plants so-called trained and experienced inspectors and their supervisors have obviously missed many of the essential principles somewhere along the line.

It seemed likely, therefore, that a book such as this is hoped to be, would prove as valuable for today's inspection forces for

instruction and reference as it would have been during the early days of World War II.

No attempt has been made to include within the covers of one book every last ramification of inspection, gaging, testing, and quality control as it exists in the present huge diversity of American industrial production. This would be impossible. It did seem possible, however, to present, explain and illustrate many basic principles and procedures which form the common denominator for most inspection requirements. It is believed that such basic information will provide a sound foundation on which the individual inspector can build additional knowledge and skills related to his specific needs. If such a foundation has been successfully laid in this text, the book will have well served its intended purpose.

Providence, Rhode Island
July 1951

CLIFFORD W. KENNEDY

Preface to the Fourth Edition

The main reason for revising Inspection and Gaging at this time is to introduce some new and important developments in the field of precision measurement. Thus, a chapter has been added to cover in considerable detail the subject of measuring in millionths and another describes the use of coordinate measuring machines. Also, material that formerly appeared as appendices in the previous edition has now been incorporated into relevant chapters to provide better continuity. Many illustrations throughout the book have been updated.

The writer feels honored for this opportunity to "carry on" for the late "Cliff" Kennedy, who was a friend and colleague. An attempt has been made to preserve the original "flavor" of the book and to use, as nearly as possible, the same plain, down-to-earth language that characterized "Cliff's" writing.

Providence, Rhode Island
April 1967

DONALD E. ANDREWS

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Any attempt to list the many individuals, friends and associates, the engineers, chief inspectors and quality managers throughout the country who have helped supply other material and experience for this book would pose a publisher's problem akin to Who's Who. Our gratitude for their help is none the less sincere though we fail to print an honor roll.

C. W. K.

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CHAPTER 1

The Need and Function of Inspection in Industry

Our five senses are basically instruments for inspection based on self-preservation, curiosity or enjoyment. We look to the left (most of us who are still living) to see if it's safe to cross the street, and listen at railroad crossings. Our noses tell us when there is a gas leak, and the taste buds warn us before we eat something that will sicken or poison us. We feel in the dark for the light switch before bumping into the furniture.

The babe puts everything in his mouth; it is his way of comparing the new and mysterious with what he knows, his manner of inspecting. We see a sunset, smell a rose, hear music, taste candy, and stroke the soft silkiness of a dog's ear.

Either for protection or gratification we are inspecting all day. Milady inspects the dress just returned from the cleaners; you try the brakes on your car after the garage has finished adjusting them. Crouching like a Mohammedan at prayer and sighting along the green from ball to cup before that critical putt is an inspection. Many inspections are so commonplace that we are not conscious of making them until something is awry. You look at the top of your dresser every morning of your life and never really notice it until one of the familiar objects is removed or something substituted for it.

The dictionary defines an inspection as the critical examination of something and the inspector in industry is supposed, by the very nature of his title, to examine products more closely than workers performing other tasks on them. But in the broader industrial sense, an inspection is a critical examination directed to some predetermined purpose. You might inspect a store show window with great care and comment only on a lack of symmetry or some equally irrelevant condition, but the head window dresser would instantly detect the absence

of an item of merchandise or the wrong price tag. A factory inspector would disregard the oil, dirt and chips on lathe turned pieces, knowing they are to be washed and nickel-plated later, and observe the shoulder burr that would prevent ready assembly in mating parts.

In the broader industrial sense, inspection, if it were necessary to define it in a very few words, might be called *the function of comparing or determining the conformance of product to specifications.*

The Study of Inspection

The subject of inspection in manufacturing plants may be approached over one of several routes. Which one is immediately chosen need not be of major concern because the many elements of the subject are so closely connected that a study of any one of them will inevitably show the need for understanding the others.

For the purpose to be served here, one road should have been travelled, at least a short stretch of it. Whoever undertakes the study of industrial inspection should have enough general knowledge of present day industrial methods, enough hours on the factory floor, so that too frequent and lengthy interruptions to explain common manufacturing operations and terms can be avoided.

The mention of shop inspection may immediately signify to many an ability to measure. It calls up visions of micrometers, height gages, surface plates, indicators and the host of measuring devices developed for the use of the shop inspector. Measurement is an important part of inspection; practice and proficiency in efficiently securing accurate measurements are essential. All the emphasis, however, should not be placed on learning this phase of inspection.

For others, the term implies visual inspection, so-called, the act of looking at parts and pieces and classifying the work by eye as satisfactory or rejectable. Visual skill and good judgment in determining the quality of shop products are assets the successful inspector should be sure to develop.

Different products, processes and types of manufacture, of course, alter details of the viewpoint of inspection. The foundry inspector thinks of such things as castings, blisters, core alignment and snagging. In the paper mill or weave room, inspection means the survey of broad areas of product or tear-

ing off a swatch for more detailed analysis. Inspection frequently includes testing, as for viscosity or tensile strength; it may involve reading electrical instruments. In a silver shop the inspector requires an expert knowledge of finishes while the candy inspector, many times, is a taster. An unique inspector is the man in the match factory who strikes and blows out 3,000 matches a day, samples of the day's production, to observe how they act in the various safety tests he conducts. These are details of procedures and techniques which are learned on the job.

Inspection also may be studied from the point of view of its function and responsibilities in the modern industrial organization as compared with, for instance, production, engineering, purchasing, et al. This viewpoint is valuable since so many inspectors fail to see the forest for the trees. They become snarled in details and petty wrangles, self-righteous when their smallest decisions are questioned, and forget that other men and departments are also interested in their assignments and accomplishments and have an equal right to breathe the free air around all of them. There is a basic framework of inspection applicable to practically every industry, which is a part of a total organization's responsibility for putting out products, and inside which the particular local pattern of inspection details is arranged.

Inspection in the Small Shop and in the Large Plant

Consider for a minute a small shop employing, say, less than ten workers. The owner is at once boss, sales manager, treasurer and foreman of this "one-man" business. At almost any time he can examine each operation in detail, inspecting the fabricated parts or completed units of the product. He knows what his customers think. He can readily check on the quality of materials or parts he buys. Furthermore, each employee shares the owner's concern and knows instantly when shabby workmanship appears in the shop. In such a group, anything resembling formal inspection is unlikely.

At the other extreme there are, for instance, the huge automobile plants where many thousands of people work on three shifts. Other thousands of dealers and salesmen distribute the cars and repair parts throughout the world. The "boss" of such an organization has only occasional opportunity to inspect comprehensively the finished product. He can practically never

examine critically an individual operation. Yet the quality of each car concerns him more, perhaps, than almost any other problem, for he knows the customer is every bit as critical of the big plant's product as he is of the merchandise offered by the one-man business.

When a shop grows larger, more and more people working in it must assume some of the responsibilities and anxieties of the owners of the business. They must perform more of the duties the "boss" still wishes he had time for. So, to an extent, an inspector represents the boss when it comes to seeing that the manufactured products conform to the desired standards.

A comprehensive treatment of shop inspection should include a study of instrumentation — gages, meters, special apparatus, visual aids, their selection, manipulation and maintenance. It should include a study of the more commonly used industrial inspection routines, the planning of an effective day's work, essential records and the elimination of unnecessary activities. An inspector, in many cases, should be well grounded in statistical quality control techniques. If he has a flair for mechanics, he is that much better equipped. He needs business sense, too, in connection with his duties, especially an instinct for detecting unprofitable routines. He should be as chary of adopting superfluous inspection procedures as a good merchant is of merchandise that won't sell. Finally, there is what is popularly known as the psychological angle. The inspector who can get along with people, influence them, get them to accept his decisions and like them, is possessed of a most valuable asset.

The Function of Inspection in Industry

A good way to look at the function of inspection is to compare the industrial organization with government. In government (American variety) there are the legislative, executive and judicial branches. An industrial organization has engineering, production and inspection departments. Where one or two legs of the governmental triumvirate are combined or missing, there is apt to be dictatorship. Dictatorships in an industrial organization may, like their political counterparts, come into existence because of the weakness of one or two of its functional branches.

Basically, whatever a factory produces is made because the customer wants it. Customers are to industry what the

"peepul" are to the politicians. Hence, in industry, what the people — the customers — want is determined largely by the sales and engineering departments. Theoretically, in most plants, the final responsibility for exactly what is to be made, and frequently how it is to be made, rests on the shoulders of the engineers. They are the legislators.

Then, theoretically as well as practically, the production department carries out engineering directions. It makes the specified products, producing them in the quantities required by the sales department, and many times following the manufacturing procedures in detail prescribed by the engineering department. The production department enforces the law — "theirs not to question why," in theory at least.

Dual Function of the Inspection Department

The products are made and are ready to be sold. Has the law been transgressed? Here is where, in the more progressive shops, the inspection department enters. Like the judiciary in government it has, in a way, a dual function. It must simultaneously interpret the law and also decide whether or not the decrees have been satisfactorily met. To this degree, it stands in judgment between engineering and production. But, operated properly, inspection performs another service. Wise court decisions are based not only on the law but also on the viewpoints, feelings and rights of the people. The inspection department, in a plant, represents the customer. This responsibility should be kept in mind in deciding troublesome shop family disputes.

In the same vein, the inspector should never try to make the laws — originate, change, elaborate or establish specifications — but, as with a court, his wise interpretations of the law, of constitutionality, if you want to put it that way, will in the end effect desirable changes in the applications of the laws.

Applying another viewpoint, it might be said that the inspector's job includes a management function and responsibility. He is assigned to do what the plant manager, the purchasing agent, the chief engineer and the production manager themselves should do, in theory, and perhaps would like to do if they had time. This assumption should offer no reason for the inspector to puff up with importance. It has been suggested solely to emphasize a degree of *responsibility* that the good inspector should assume. Because the inspector does take over

the responsibilities of quality and performance the sales manager can devote that much more attention and diligence to where and how the product can be sold, the purchasing agent to better and better sources of supply, the engineer to design and methods and the production worker to the actual manufacturing operation.

In manufacturing, the inspection act itself entails the comparison of a product with the specification or some standard. It includes determining whether or not the part, product, or batch is free from faults, blemishes, or defects, that it is made to prescribed tolerances, sizes, color, taste, or texture. A portion of manufacturing inspection frequently overlooked is the responsibility for making sure that the correct materials have been used and especially that all of the processing operations have been performed.

As an industrial activity, inspection becomes one of the planned and specific factory operations as much as drilling, hardening, time keeping, or receiving. Shop inspection usually involves repetitive, routine operations in some form or degree.

Need for Inspection

Let one man make one thing, another man make a second thing, and a third put the two together to form a subassembly or product, and you have a basis for inspection. When different people make parts there are likely to be as many different standards of workmanship. Few instances occur in present day manufacturing where a product is made complete from raw materials by a single worker. The whole tendency is to subdivide a job into a series of separate operations. Operations are also frequently performed on products at widely separated locations and time intervals. Parts are routed, for example, to milling machines and then upstairs to be drilled. Frequently they are sent out of the plant for plating, say, or for hardening.

Years ago, if a man wanted a screwdriver, he cut off a piece of steel, heated, hammered, forged and ground the blade. He turned a bit of hardwood for a handle or whittled it out with a draw shave. Nowadays the stock is cut to lengths by machine in one place, the blades are drop forged in dies, tempered in hardening furnaces, and then ground by another group. The handles are turned in the woodworking department by one man and the holes in them bored by another. They go over to the paint shop to be dipped and baked. The ferrules are blanked

and drawn on presses somewhere else. Finally the screwdrivers are assembled. A dozen workers, or more, have had some part in making a single screwdriver.

In addition — or as a consequence of specialization — the individual worker is interested almost entirely in his own task and cares little about the effect of operations preceding or succeeding his. Repetitiveness, monotony, even drudgery, enter in. The operator too often, in modern industry, is less an artisan and more an automaton.

Engineers and methods experts are employed to devise machines, techniques and routines for faster, simpler, and cheaper production. Incentive plans are added under which the worker's pay envelope depends considerably more on the quantity of units he completes than on the quality.

The collective responsibility for quality of several operators never adds up to the care displayed by one man, himself performing all the operations; the growth of a business and an increase in the number of workers dilute individual responsibility. So the "vitamin tablets" of inspection must be added to the industrial diet in order to insure healthy products.

In the larger organizations, the continuous pressure of technical improvements in methods, tooling and equipment, the effects of time and motion study, and the turnover in help which seems an inevitable consequence of expansion — these and similar conditions all result in the production of increasing quantities of defects, scrap, and rework unless steps are taken to check them. Systematic, routine inspection seems to be the best means. Cost reports universally indicate savings in scrap and rework that are more than substantial enough to pay for an inspection setup when it is properly installed.

Some plants employing, say, from three to fifty people seldom consider or adopt formal inspection procedures until the combination of continuing growth and complaints from customers makes a routine examination of its products necessary. At first, something like a formal inspection operation may be initiated on the products just before they are packed for shipping. Occasionally, too, a need arises for examining parts, materials or subassemblies that are purchased for more or less direct use in the products the small factory is making. So an inspector is hired or someone is assigned to that routine. In some such manner the inspection procedure gets a start and grows to be one of the manufacturing routines.

Final Inspection is not Enough

Very shortly after the final inspection of finished products is instituted, it is discovered that no product is better than the components that make it up. Then inspection is extended. The various parts are to be inspected before they are assembled. It is not only more economical to discover defective units in the early stages of manufacture but many times it is impossible to test or inspect an assembled product in such a manner as to detect surely defective workmanship buried inside the article.

It is cheaper, for example, to test a radio condenser as it is made than to tear down the whole set later in order to replace a dud. A motor's field can be given a high voltage breakdown test as it is made, a type of test which cannot be as safely applied after the field coils are in the stator and the armature assembled. Just one warped or loose wrist pin connection inside the piston in one of the cylinders of a 5,000-dollar automobile can completely ruin the owner's pleasure in that car. Furthermore, the troublesome wrist pin may not make itself evident either at the normal factory test or when the dealer demonstrates the car on a short run around the city. The defect may not "speak out" until later at seventy miles an hour or when the car is toiling up a mile high mountain pass. In most modern industry there is need for a detective agency, some portion of the organization specializing in and responsible for uncovering actual or potential hidden defectiveness.

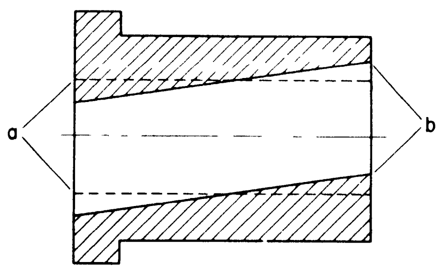


Fig. 1. Improperly drilled motor bearing.

Another economic reason for inspection as a part of the manufacturing routine is the fact that later operations so many times fail to correct previous defectiveness. Suppose a small motor bearing is drilled as shown at *b* in Fig. 1, rather than correctly as the dotted lines *a* indicate. The reamer, in the next

operation, will follow the originally drilled hole no matter how solidly the reamer and bearing are chucked or held. After a motor is assembled with such an out-of-line bearing, there will be vibration, heat and rapid wear, at least, if the armature shaft doesn't actually freeze in the bearing.

Inspections paralleling certain production operations help to prevent cumulative defectiveness in products. Weaving faults may be blamed on the loom, but frequently the trouble can be traced back to the spinning frames, to carding or even to some carelessness in scrubbing the original sheared wool. You recall the jingle: "For the want of a nail . . . the battle was lost." Modern industry more and more relies on inspectors to detect omissions in the process which accumulate error on error like a snowball rolled down hill.

Mass Production Requires Interchangeability

Most present day products are put together under so-called assembly-line methods. Take a factory that makes electric flatirons. You will see a long bench or conveyor at which operators sit or stand. On and above the bench you will see sole plates, among other things, and lengths of cord, nichrome heating units, plastic handles, asbestos pads, electrical connector parts as well as trays of screws and bolts. It makes no difference that some of the parts were made three months ago and others just yesterday, or that plastic parts were molded by a concern half way across the continent. They must all fit together accurately — and quickly.

Our whole system of producing large quantities of products at low prices hinges very considerably on interchangeable parts. In the flatiron assembly line, it makes no difference which sole plate an operator picks up to fit with a heating unit and other parts selected entirely at random, the assembly goes together because the parts are interchangeable. The same idea shows up in the weave room where a truck full of spools of yarn are moved up to the loom. It makes no difference whether the loom fixer racks up a particular beam of yarn on the right hand side of the loom or the left or in the middle so long as the yarn is uniform enough to make the spools truly interchangeable. Complete interchangeability of parts is economically essential in mass production of fabricated products.

The automobile epitomizes interchangeability for most of us. At the same time it brings up the subject of repair parts.

Whether it is a king pin, clutch plate or door handle, we expect the purchased repair part to replace accurately the worn or broken article.

Interchangeable parts, then, reduce assembly costs by eliminating nagging and costly delays in selecting, filing and fitting. Interchangeable parts permit quick, cheap and satisfactory repairs. But the most important factor in connection with truly interchangeable and accurately fitting parts, perhaps the one most frequently overlooked by factory people, is the fact that they make better, longer wearing, more reliable products when assembled together.

The engineering department is charged with the responsibility for designing parts that will be interchangeable; it establishes tolerances which makes this possible. Frequently it helps in developing the processes and methods to assure interchangeability. The production department then assumes the duty of producing the parts as specified; in the end it is responsible for *making* them interchangeable. Finally, the inspection department must determine the fact that the parts are interchangeable, or not.

Special Duties of the Inspector

In the routing of pans, boxes and trucks of parts from machine to machine, a batch of work may be carelessly or inadvertently detoured and miss an operation. Certain small cam sections in an intricate weaving machine are to be shaped, milled and drilled. Then they are to be hardened before a final grinding operation. Suppose it is discovered after they are hardened that the drilling operation has been somehow overlooked. There is not only the nuisance and cost of rerouting the work back to drilling but the pieces must first be annealed. Then they must be hardened again after the omitted drilling job has been performed. By that time they may be warped or ruined beyond repair. Add to this the probable expense of someone's lost time waiting for the pieces to reach his operation. An inspector can serve profitably as a sort of truant officer to prevent such occurrences.

Inspectors are frequently called on as specialists to make selections of parts or perform sortings. The normal hardening process, suggested in the paragraph above, may have produced a few unpreventably distorted pieces and the inspector may be asked to pick out the cripples. Mica sheets, for another

example, must be selected and classified for thickness by gaging. At the same time streaked, cracked and impure sheets can be seen and thrown out. Nature never makes a one hundred per cent uniform product.

There are occasions where an operation, usually because of shortcomings in equipment, is known to produce goods that in appreciable quantities fail to meet the specifications. Under such conditions, at least as a temporary measure, inspections are deliberately instituted for the purpose of culling out defective units. For the time being, such an inspection (commonly known as sorting, detailing or screening) may be a cheaper expedient than to attempt to re-equip, slow down or otherwise modify an operation to produce within specification limits. Or again, sorting or detailing will expedite the delivery of orders, segregate scarce or expensive parts for salvage operations or effect savings in subsequent assembly operations. For example, balls used in ball bearings are gaged and sorted into groups, each group having a predetermined diameter. The ball races are similarly classified. If size A balls are then assembled within class A races more nearly perfect ball bearings are secured. Such an operation is known, commercially, as selective assembly.

The Inspection Department's Second Responsibility

If the inspection department should be said to have only two responsibilities, the second one, in addition to assuring conformance, would be that of judging appearance. This includes the questions of workmanship and standards, to be taken up in detail subsequently.

From mouse trap to mansion, the choice of which product — yours or your competitor's — the customer will take may well hinge on its appearance either at first glance or after prolonged scrutiny. Standards of appearance falter under the repetitiveness and pressure of incentive-paced production and someone must stand guard over them. The worker, absorbed in his tools, overlooks appearance. We fail to notice how shabby our everyday shoes have become until we go in to buy a new pair. The artist stands back from his picture but someone else can more readily point out where the coloring is dull or the shading too deep. Impartial self-criticism is difficult.

In industry the inspector is not only trained as a specialist in the early detection of many substandard details which the

production group, naturally more intent on quantity, ignore or overlook, but he is equipped with special apparatus for the purpose. He may use a microscope, for example, a special type of light, a color comparator or chemical analysis apparatus. He has gages perhaps that magnify almost intangible changes of dimension on indicators.

Classifications of Inspection

Industrially, inspections have come to be typed or classified in terms that are descriptive of the sort of work performed or the location of the inspection in the process or shop.

According to the general sort of labor involved, we have,

Manual Inspection
Visual Inspection
Test Inspection
Mechanized or Automatic Inspection

Generally descriptive of the area in which the inspection is performed, there are,

Process Inspection
Batch Inspection
Final Inspection
Receiving Inspection
Tool and Gage Inspection

These may be broken down into other operations, such as,

Patrol Inspection
First Piece Inspection
Sampling Inspection
100 Per Cent Inspection

Further subdivisions of inspection work and relevant terminology, common in industry, will be taken up as each major division is discussed farther on. Inspection procedures in the average factory embrace many of the classifications listed above, in various combinations, though different local names may be used for the same general type of inspection.

Inspection personnel are also classified under a variety of names. There are sorters or detailers — and inspectors, of course. As the work involved becomes more technical and administrative, the expression inspection engineer appears. Lately, we are hearing about quality analysts and quality control engineers. In the upper brackets of inspection department supervision there are inspection foremen, chief inspectors, quality superintendents and quality managers.

As the lists above imply, inspection work is often specialized. One group of inspectors may do only visual work day in and day out, becoming fast, adept and expert. Others are trained in gaging, testing or in handling special apparatus. Specialization in inspection follows the products and operations. One man may know all the details of receiving inspection but not much of what to look for in the finished product his factory makes and ships. A foundry inspector could not readily pass on the conformance of wooden handle grips made over in the wood turning shop.

Inspections are often combined with production operations. The inspector may, for instance, screw on a nameplate or stamp a serial number as part of his routine. Calibrating and indexing are often assigned to inspection groups. The inspector may be asked or required to keep records, not only his own, but for stock, production control or cost accounting. Under some systems, a worker cannot be paid accurately until his work is certified in some fashion and the inspector, many times, is in the best position to say that all required operations have been performed.

Extra Duties of the Inspector

Inspection covers a miscellany of other industrial items. Inspectors are sent into shipping departments to sample and by various means discover shipping errors or sloppy, ill-secured cartons and crooked labels. Where the external appearance of the package is a strong factor in its eye appeal on the store counter or shelf, formal inspection is frequently required. To hold the inspection department responsible for checking all tools, dies and jigs is a fairly common present-day practice, this work frequently including the testing and calibrating of gages, measuring instruments and test apparatus.

Inspectors are assigned to trouble shooting, and sometimes actually to expediting. Where products are failing at a certain operation an inspector is assigned to trace the causes of the trouble, the trail often leading him back not only through a series of previous operations but perhaps to the raw materials themselves. In a similar vein, if certain parts fail to show up for subsequent operations in accordance with the production control schedule, an inspector may have to take journeys farther back into the shop to find out why and report on the reasons for the delays.

Parts, goods and products may become damaged in transit through a plant. In one shop, many hundreds of carefully ground and lapped disks were ruined daily for assembly purposes because everyone handling them tossed them carelessly into tote boxes or onto benches. The parts became badly nicked, scratched and dented. Inspectors were employed to attempt to police or control the careful handling of parts. In an ammunition plant inspectors were assigned to examining empty tote boxes. Powder from loaded ammunition components occasionally spilled out and, unless the boxes were given careful daily washings, dangerous accumulations of explosives could occur.

In his shop area, an inspector may also be asked to report on general conditions (which nevertheless affect the quality of the products) such as the maintenance of machines and equipment, the lighting or the housekeeping.

Where scrap or junk has been made or where parts have been rejected simply on the basis of being somewhat over the specification, an experienced inspector is frequently present to aid in devising rework operations which may in one manner or another salvage losses. A few progressive plants call in an experienced inspector or inspection supervisor to take part in product design and process or methods planning because of his peculiar and unique shop knowledge. An inspector many times can foretell why or where a planned part, product or operation will fail the desired specifications.

Good inspection exerts a worthwhile though intangible, perhaps, moral influence on an operation, department or a whole shop. It is a common saying in manufacturing that, in the interests of operating economy, the inspection force should be reduced to a minimum, of course — but never take away the last inspector. The fact that there are traffic officers restrains many of us from driving sprees and disobeying traffic rules even though for long periods we don't see one "inspecting" traffic.

In one form or another inspection has become an integral and essential division of manufacturing routine. It will be found on most factory organization charts along with sales, engineering, production, purchasing, stores, maintenance, the tool room or first aid, and the inspector shares in the cooperative effort that makes up a successful manufacturing enterprise.

CHAPTER 2

How Specifications Aid the Inspector

If the primary duty of an inspector is to compare conformance with the specification, then the natural question arises: What is the specification?

When a mother sends her boy to the store for a spool of black thread, he and the storekeeper are in trouble if he brings home blue, green or brown. Black thread was specified. Life is crammed full of specifications. Working hours are from 8 A.M. to 5 P.M. with an hour at noon. Specifications! A railroad timetable is a set of specifications; so is a concert program. Or a cook book. The number you dial on your phone or repeat to the operator is an exact specification. Almost any advertisement you read in newspaper or magazine contains specifications, direct or implied, and you are disappointed when the purchased merchandise fails to live up to your impression of those specifications. Catalogues, as contrasted to advertisements, are much more specific.

Many specifications have been set by tradition. They have become common standards. Do you recite the specifications for muslin, a pair of shoe strings or ten-penny nails as you casually purchase them? Other specifications are natural chemical compounds or reside in formulas that have been handed down from century to century. We buy sugar, salt or ale without any particular reference to specifications except, perhaps, that we are attracted by some particular brand name or feel that a certain supplier more successfully keeps impurities from his product.

There are definite specifications back of practically everything you use, from a safety pin to a skyscraper. One reason for a high standard of living such as exists in this country today is our ability to specify our wants pretty exactly. And get them!

The Blueprint as a Specification

In the majority of manufacturing plants, the most common form of specification is the blueprint. On it the engineer usually describes the particular part or product in minute detail. The blueprint conveys the process engineer's and the shop man's ideas of how a part should be made; it includes the designer's ideas so that the part will fit and function properly in the assembly; many times it represents years of experience and trial and error; directly or indirectly it indicates what management and the customer think the part or product should be like.

In the physical sense, a blueprint is a developed photograph. Rather than light and shadow affecting sensitized paper, however, the blueprint is made by having strong light shine through the original drawing (or tracing) and the chemical change leaves white lines on a blue surface. Other types of sensitive paper will produce a black print (black lines on white paper) or a brown print. Some stress has been given this detail because the blueprint, black print or brown print is the exact mechanical, the legal duplicate of the original drawing. It saves ruining an original drawing by using it on the shop floor. Some shops, too, issue brown prints in place of the traditional or routine blueprints in order to emphasize certain critical, special or important work.

Blueprints portray a huge variety of products, from battleships to bullets, from an Empire State Building to an inkwell. There are assembly prints and detail prints. Their whole purpose, of course, is to transmit the idea of what somebody wants to those who are to make it, and in so doing, they vary through a tremendous range of complexity. In the manufacturing plant, they may show an extremely simple part, such as Fig. 1 in Chapter 1, or they may show a complicated assembly of parts.

Reading Blueprints

If the blueprint is the most common form of manufacturing specification, the inspector naturally must know how to read one. To conserve time and space for the purpose to be served here, it will be assumed that the reader has a working knowledge, at least, of blueprints — that he has had some practice in reading them. More important to the immediate subject are certain elements in connection with drawings and blueprints which pertain especially to the inspector's interpretation of the specification illustrated by the blueprint.

Be Sure to Get the Correct Print

The number one question for the inspector who picks up a blueprint is whether or not it is the official or authorized print for the particular purpose. In most shops the question can be answered by asking another one: Is this the very latest print?

One logical answer might be: Refer to the print the man working at the machine is following. Surely he would not be allowed to use so much time, material and equipment making a quantity of incorrect parts. While the answer is logical, it is not always, unfortunately, the correct one. Many factories have set up systems with iron clad rules under which it would seem impossible for production operators, tool makers and machinists to continue work with anything but the very latest blueprint information. Yet they do — time after time — and it becomes an inspector's duty to see that both he and the operator are provided with correct specifications.

There are a number of reasons for this sort of trouble, carelessness, habit and laziness leading the list. The engineering department may alter a specification, for example, and duly send out copies of revised prints, but the latest issues may rest on a foreman's desk for days among unread "shop mail."

Check for the Latest Revision

Revised blueprints almost never look a bit different than the superseded copies on the shop floor. Revision notices, blueprint dates and authorized signatures usually appear in somewhat obscure boxes in the formal margin or border of the print. Hence, the use of superseded prints is somewhat excusable.

Not only may the revision notice be somewhat obscure, but the very specification change itself may be so slight, yet important, as to escape attention. Observe print A in Fig. 1; then look at the revised copy, B in Fig. 1. It takes more than a casual glance to see that one of the tapped holes has been changed from ¼-20 thread to ¼-28 thread, the engineering department having decided for some good reason to use a fine thread.

One system for issuing revised prints is by messenger directly from the engineering department, who not only personally distributes the latest copies, but also simultaneously hunts for and himself destroys the superseded copies. Where the factory system is inefficient, the next best step is for the inspector to assume responsibility for securing and using the latest revised prints himself.

For the inspector, ignorance of the law is no excuse. If he is to measure conformance, he always must be sure of the specifications.

Check for the Correct Part

The second and similar step, where blueprints are to be relied on in connection with an inspection, is to be sure that the print for the *correct part* is at hand. Usually the particular unit is clearly defined on a print by a prominent part number. Even though considerable prominence is usually given the part number on a blueprint, it is still necessary to warn the inspector to double check it before proceeding with his work. As an example of what is meant, part numbers 123K-B83 and 128K-B83 or some such combination as 123X-B38 can all be readily mistaken for one another.

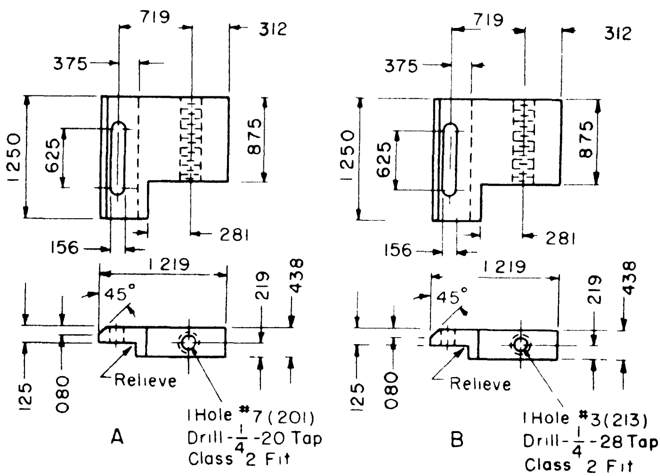
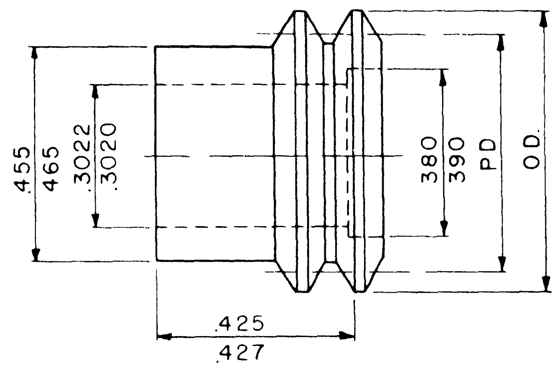


Fig. 1. (A) Original drawing of a small part. (B) Revised drawing showing changed thread size.

In addition, the parts themselves may be closely alike and look the same to all outward appearances from a quick glance at their blueprints. In the case of the part illustrated in Fig 1, for instance, it may be decided, because of the need of supplying old model repair parts, to give part B (Fig. 1) another part number rather than to consider part B a revision of print A (Fig. 1) and the two part numbers might have been catalogued as #1248 and #1249.

Practically all shops have some form of shop or production orders. The part number of the product to be made is used in the orders. The inspector verifies the use of the proper blueprint by referring to the manufacturing order or memorandum for the correct part number.

Many blueprints show the dimensions and specifications of more than one part on a sheet. Sometimes a dozen different small parts, with their part numbers or letters, appear on a single blueprint. On the other hand, the blueprint may portray a single outline with a table of dimensions or specifications for different sizes of the particular kind of part as shown in Fig. 2.



PART NO	MODEL LETTER	RANGE	O D	P D	WIRE SIZE	WIRE MEASURE
AL-522	A	4-6P	7274	6553	09623	79963
AL-529	B	7-10P	6553	6120	05774	69862
AL-523	C	11-13P	6303	5970	04441	66358
AL-524	D	14-20P	6011	5795	02887	62280
AL-525	E	22-30P	5831	5687	01924	59750
AL-526	F	32-40P	5741	5632	01443	58489
AL-534	G	44-56P	5663	5586	01031	57406
AL-544	H	64-80P	5605	5551	00722	56594

Fig. 2. Drawing with tabulated data showing parts having same shape but different dimensions.

Except for the fact that the sort of mistake, the type of carelessness, mentioned above happens to be quite commonplace on the average factory floor or in an inspection crib, it

would seem at first glance almost ridiculous to need to warn an inspector to (a) know what part number or symbol or class of part or product he is about to inspect; to (b) verify the part number from the manufacturing order, and to (c) be sure he has the latest authorized blueprint or specifications.

Make Sure of Mark-overs and Sketches

Very often an inspector will run across a blueprint on which some dimension, tolerance or instruction has been changed — marked over — in, say, pencil, crayon or ink. Many shops permit this practice. Most organizations do have a definite routine for making authorized and official blueprint changes, but it may take a matter of hours, if not days, to get the drawing changed and new blueprints out on the manufacturing floor. At the same time it may seem necessary to those in charge to execute a desired change immediately. Hence the expedient of marking over prints on the factory floor. The inspector need only question the authority of the red pencil revision to make sure that it is not already superseded by still another penciling over. Such informal changes should be signed or initialed and dated by the engineering or manufacturing executive authorizing them. To the inspector, a "mark-over" without signature or initial should be about as valid as an unsigned bank check because, once in a while, unauthorized factory personnel attempt blueprint changes as a sort of emergency expedient.

The same frame of mind and watchfulness should be displayed toward free hand sketches and the like, which are not uncommon on factory floors. (Even a sheet torn from a catalogue has been known to serve as an official print.) All such informal specifications should be properly initialed and dated by someone in position to assume responsibility.

Throughout his career, the inspector is faced with the problem of determining correct specifications, of trying to find out exactly what is wanted, and of keeping abreast of changing conditions. Like any good judge, he must read the law continually. And he must be sure of the official character of any document he deals with.

Is the Material Correct

In his examination of a blueprint, preliminary to inspecting the corresponding manufactured part, the inspector should next make note of the type of material called for: cast iron,

brass, machinery steel, aluminum, or whatever it may be. It probably seems peculiar to put the question of material high on the list of things to be looked for when checking any product against its blueprint, but one oversight not uncommon in manufacturing, ridiculous or impossible as it may seem, occurs when parts or products are made of the wrong material. The blueprint of a casting, for instance, may call for bronze. But a chain of errors, starting perhaps in the engineering or purchasing department, may cause the pieces to come in as cast iron. A sudden change in long standing specifications frequently starts the trouble. Both the machine operator and the inspector, accustomed to the cast iron, fail to notice the new specification. A similar error occurs at times in connection with screw machine parts made from rod. The stockroom may have inadvertently supplied stainless steel, for example, rather than the specified drill rod.

Order of Making Measurements or Observations

As the experienced inspector studies a new blueprint he is probably looking for the more important dimensions and tolerances. In other words, he seeks out the items and elements in connection with the manufacture of the part or product he is about to inspect which will require the greatest attention and care on his part. Usually the tolerances and notes supplied by the engineer or draftsman give him good clues. His own manufacturing experience and his particular knowledge of the product guide him, too, in selecting first those "characteristics" of the part or product he should perhaps pay closer attention to in the course of his inspection. What is meant here can be simply illustrated by referring to Fig. 3.

Without knowing anything specific about the particular part or product of which Fig. 3 is a partial drawing it is reasonable to assume some sort of axle or shaft with a shoulder flange against which something — a wheel, a pulley, a crank arm perhaps — is to be tightly clamped. Anyway, in measuring and checking a batch of such pieces, the inspector is cautioned by the very tolerances themselves, as shown on the print, that certain elements of the shaft require greater care in manufacture and closer observation at inspection.

Evidently the designer was concerned with the .748-inch diameter. It cannot be oversize at all; and undersize by not more than .0002-inch. In addition he has asked for an extra fine

surface finish as shown by the symbols *f* and *f*. The inspector's mind immediately turns to consideration of the available high precision measuring instrument he can obtain to check this diameter with. On the other hand, he can use micrometers or vernier calipers to measure the diameters of the flange and the long part of the shaft, which the print shows as 1.875-inches and 1.125-inches, respectively. In these latter dimensions, an error in manufacturing of even .010-inch probably would be tolerated and an error of a thousandth or two in the way the inspector made the measurement would cause no harm.

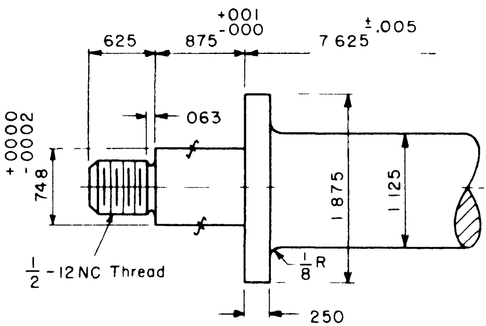


Fig. 3. Drawing of piece-part showing some of the dimensions with which the inspector is concerned.

The inspector's second choice of a "critical" dimension on the part shown in Fig. 3 would be the length of the precision turned and ground shaft section — marked as $.875''^{+.001''}_{-.000''}$ on the print. He could check the .625-inch length of threaded section and the .250-inch thickness of the flange with a steel rule, perhaps, and secure sufficient accuracy for the purpose of inspection. But he must be sure to arrange for an accurate measurement setup, and sufficiently precise instruments when he verifies the shaft segment length of $.875''^{+.001''}_{-.000''}$

If the several sections of the shaft shown in Fig. 3 are to be classed in order of measurement importance, the inspector would then, as the third mental step when he looks at the blue print, select the threaded end of the shaft and plan to secure a suitable ½″-12 NC thread gage.

If for no other purpose than to recommend reasonable orderliness in going about an inspection assignment, the selection

of information from a blue print has been classified in the following order of importance:

(a) Be sure the blue print is for the correct part number.
(b) Verify it against the shop order.
(c) Be sure the blue print is the latest, authorized, official, revised version.
(d) Verify the official character of all blue print mark-overs, of all free hand sketches and the like appearing on the manufacturing floor.
(e) Check for the kind of material specified, both on the blue print, the shop order and at the operation.
(f) Catalogue somewhat in order of importance the dimensions and specifications which the print shows may require extra attention at the inspection.

Blueprint Notes Should be Read

It is wise next — adding another letter, (g), to the above list — to read all notes the draftsman may have put on the drawing. Such additional specifications, warnings and information may not outrank, in importance at the inspection, some of the regular dimensions to be verified. Nevertheless, a definite place in the routine of reading a print should be assigned to notes and special information, otherwise, the inspector may neglect a special piece of information. Good habits are established as easily as bad ones.

An example of the effect of blueprint notes is shown in Fig. 4. Among the several draftsman's notes is one which directs the machinist to spot face the casting where a .375-inch hole is drilled and reamed through it, an operation just about as important for the use of the product as the hole itself, but one which the operator may readily neglect. On this same print is another note which orders two surfaces to be machined square *but not painted.* The paint shop might overlook this specification and fail to mask these two surfaces prior to spray painting. In like manner, the paint shop could forget to mask the "spot face" mentioned above.*

* Masking is a term used in paint shops. It means that surfaces which should not be painted will be covered with metal or wood templates, strips of paper or tape, or greased. Holes are frequently filled with wood plugs. So protected, the part or product may be quickly sprayed, dipped or brushed. The masks are designed to be readily removed after the paint is applied. Wood, cardboard and metal masks are used over and over again.

The draftsman's notes on Fig. 4 also tell the machinist the exact size tap drill to use in making a tapped hole. If too small a tap drill is selected, the tap that is subsequently used may bind, even though the machinist succeeds in threading the hole without breaking the tap, and, in addition, the mating screw will quite likely bind, strip or not enter at all at assembly. When the theory and elements of screw threads are studied in a chapter farther on, the reader will not only appreciate the draftsman's good sense in specifying tap drill sizes but also, more clearly, why an inspection should include a check on the size of tap drill used by the machinist.

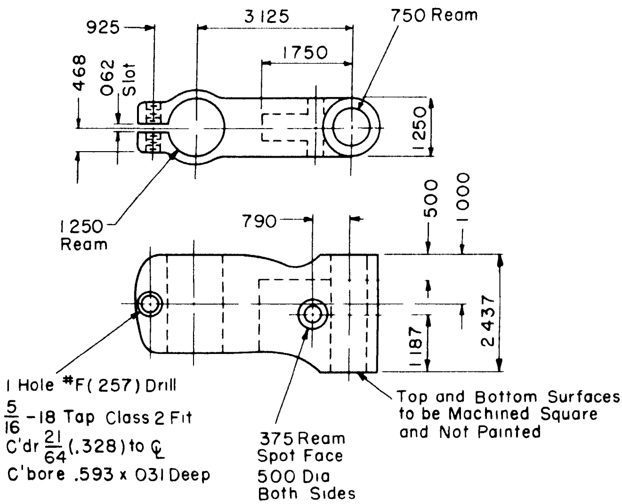


Fig. 4. Drawing that shows how notes are used to supplement dimensions.

The notes on the print shown in Fig. 4 emphasize, too, the value, to the inspector, of knowing where and how the particular part is to be used in the assembly or on the finished product. If, for example, he knows that a shaft will go in the .375-inch reamed hole and that the shaft is to be turned by a handle attached to it, the hub of which will normally rub against the side surface of the casting, the reason for the smooth spot face called for becomes apparent. The value of knowing the subsequent use of any part or product about to be inspected will be emphasized again in the later sections discussing the subject of standards.

Another form of draftsman's notes concerns surfaces that are to be finished, or machined, in contrast to those that are to be left as the foundry mold, the forge die or the steel mill roll formed them. The symbol *f* is used to mark finished surfaces.

The practice of calling for finished surfaces with the symbol *f* has developed until now it has more to do with the actual grade of surface finish. The *f* (see *A*, Fig. 5) may mean a certain degree of fine finish and an *ff* an even better degree, as at *B* in Fig. 5. In late years, other and more exact symbols

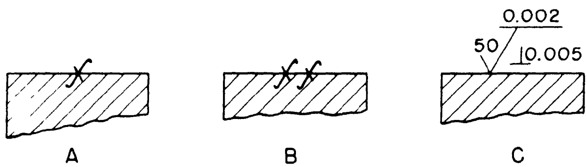


Fig. 5. Two ways of denoting degrees of surface finish. Early method: (A) Fine finish; (B) Finer finish than at (A). (C) improved method gives specific data.

for surface finish have been adopted, to keep pace with improving methods for obtaining finer surfaces, as illustrated at *C* in Fig. 5. The meaning of this type of designation and the technicalities of surface finish, or surface roughness, are discussed more fully in a later section on surface standards.

Perhaps these several examples will impress the inspector with the necessity for having a definite step in his routine; a particular time during the reading of a blueprint, in which he will mentally emphasize draftsmen's notes. Prior knowledge of all specifications enables a more expert inspection of the product.

Sequence of Operations Should be Noted

The next regular chore on the list of inspection do's in connection with reading a blueprint is to know or determine the particular operations to be performed on the part or product. Only one of the total number of operations indicated is to be performed, ordinarily, at any one machine or at any one point in the process. Sometimes several operations are carried out at one location, but not all of them; occasionally the part shown on a print can be completely fabricated on a single machine. Some shops do furnish prints of semi-finished

parts, but in most factories the blueprint describes the completed part, and operation sheets, or their equivalent, are relied on to detail the several operations or subdivisions of the total job. (Operation sheets are described in a section farther on).

To illustrate the inspector's interpretation of a blueprint in terms of the individual operations performed on the part, refer to Fig. 6. Here is the sketch of a short shaft which is to be turned, in which a keyway is to be milled, and through which a hole is to be drilled. If an inspection takes place at the lathe, the inspector would measure dimensions *A, B, C, D, E* and *F*. After the pieces leave the milling machine he would verify *G, H* and *I*, and at the drill press he would check

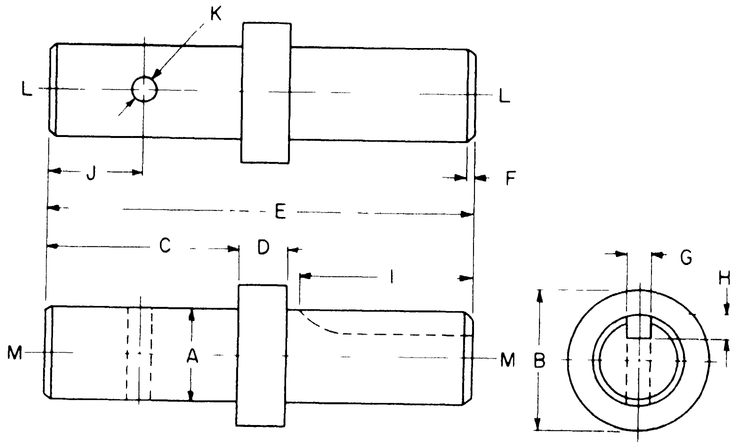


Fig. 6. Dimensions *A, B, C, D, E*, and *F* are measured after lathe operation; Dimensions *G, H*, and *I* after milling; diameter *K*, dimension *J* after drilling.

the hole diameter *K*, making certain also that the hole has been drilled on center *L—L* — checking dimension *J* also — and perpendicular to center line *M—M*.

In other words, an inspector must usually select from a blueprint the dimensions and notes pertinent only to the machine, operation or station in the process where the particular work is being performed.

Watch for Conditions Implicit in the Drawing

When a draftsman draws a picture of a part there are certain things he expects will be obtained when the part or product is made, even though his drawing does not explicitly

cover such details with actual dimensions or notes. For example, if he calls for a simple tongued piece similar to that sketched at A in Fig. 7 he expects it to be closely like A and not in any one or several of the different shapes that can actually emerge from a milling machine, as shown in exaggerated fashion at B, C, D, et al. of Fig. 7.

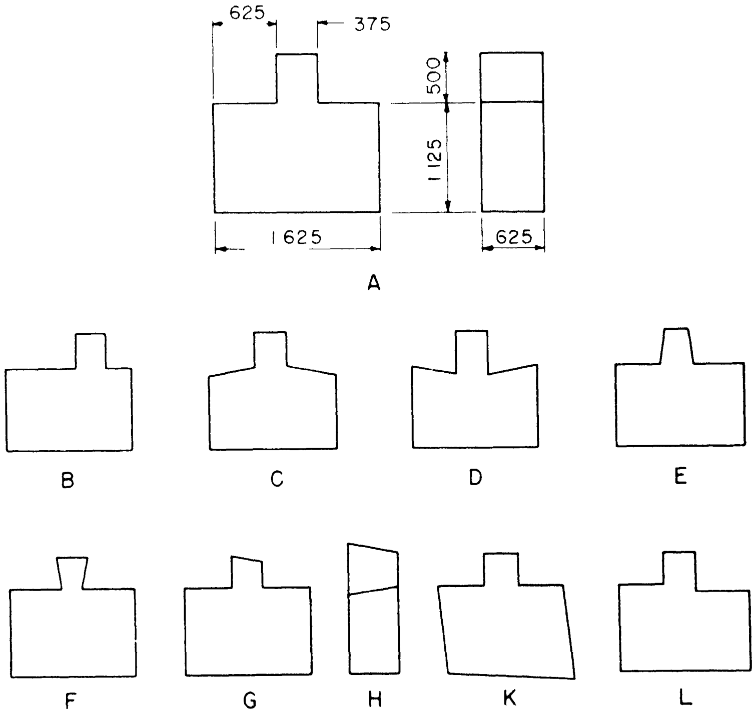


Fig. 7. (A) Drawing giving dimensions and shape of part. (B), (C), (D), (E), (F), (G), (H), (K), and (L) show possible variations from (A) due to improper machining.

Where a horizontal and vertical line intersect on a drawing the designer intends a 90-degree angle though he makes no special note of it on his drawing. If two lines are parallel, the two surfaces represented are supposed to come out parallel from the machining operation. A hole is supposed to be bored straight and not on a slant; it is supposed to be round and not oval.

As an example of the possibilities an inspector needs to be on the alert for, observe the several types of holes pictured in

Fig. 8. In this case the drawing called for a round, straight hole of diameter *A*. Any drilling or boring operation has a tendency, however, to produce one of the forms listed in Fig. 8. Though in each case the dimension *A* is met, at one point at least, it is evident that the other difficulties pictured could make trouble at, say, assembly.

Thus, in addition to checking the part for conformance to *explicit* dimensions and instructions given on a blueprint, the inspector must watch for conditions *implicit* on the print.

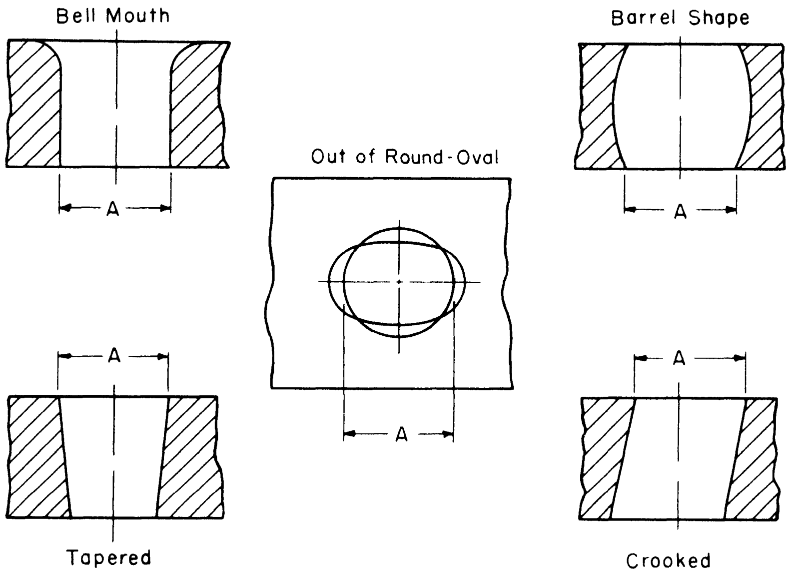


Fig. 8. Possible variations of a supposedly round, straight hole.

Common terms for such items, in addition to those listed in Fig. 8, are squareness, parallelism, waviness, warp (distortion), sprung, kinked, eccentric, run-out and out-of-line.

Lack of Surface Parallelism

Shaper, planer, milling machine and grinding operations produce inspection problems in parallelism — waviness and warp for example. An effort has been made to picture such conditions, in exaggerated form, in Fig. 9 where the blueprint requirement of perfect rectangularity is illustrated at A but where lack of parallelism, waviness and warp show at B, C, and D respectively.

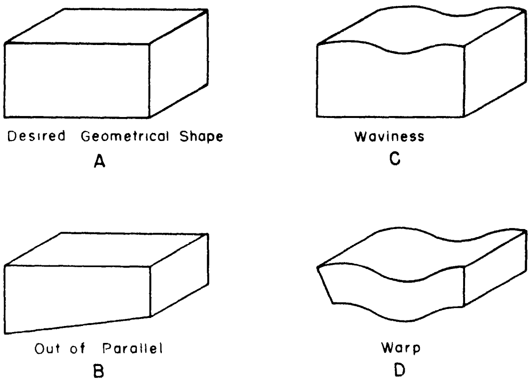


Fig. 9. (A) Rectangular block. (B), (C), (D) Variations due to improper machining.

Undesirable Shaft Taper

Taper is a form of lack of parallelism. In some instances front taper is spoken of, or back taper, especially the latter. Taper (front taper) and back taper are illustrated in the views of a shaft section in Fig. 10. Here again, dimension *d* has been met at least at one point on the shaft sections at B and C.

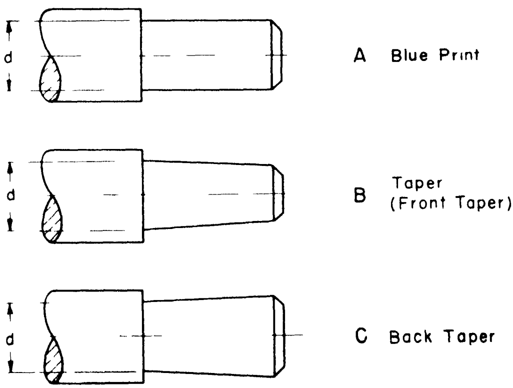


Fig. 10. (A) Shaft required. (B), (C) Variations due to improper machining.

If a shaft like that at B in Fig. 10 were assembled in a hole in a mating part, it could bind in the hole (because of the wedging effect of a front taper) or, if the hole were large enough, it could make an extra loose fit. The back taper condi-

tion of C (Fig. 10) causes even more trouble in the assembled product. When the shaft with back taper is assembled in a hole, especially if the hole is on the small side for size, the fit is tight and the assembler instinctively forces the shaft in. The large or bull end of the back-tapered shaft section then broaches the hole, in effect, and a loose fit between shaft and hole is inevitable. All this, even though the shaft was intrinsically made to the correct diameter.

Concentricity, Run-out and Eccentricity

The terms concentricity, run-out and eccentricity are used more or less interchangeably in the shop and on blueprints, with run-out the favorite shop term. Where two holes or shaft sections are not on the same centerline they are not concentric. While the shop calls the condition run-out, the draftsman may put a note on the drawing calling for "concentricity within .0002." However, the actual, measurable error is eccentricity — the lack of concentricity.

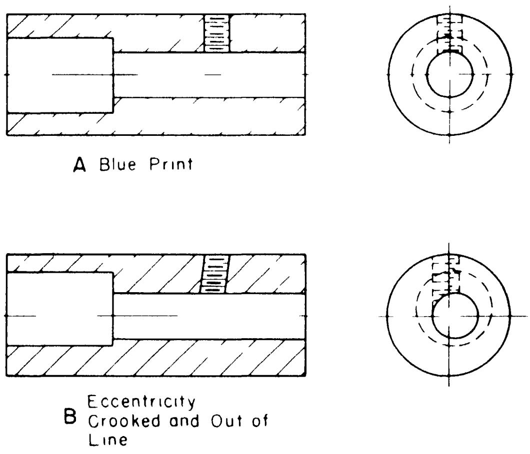


Fig. 11. (A) Tapped hole called for on blueprint. (B) Crooked and misaligned tapped hole actually produced.

Part A of Fig. 11 illustrates a coupling piece as the designer wanted it and B in Fig. 11 shows a few of the possible combinations in regard to eccentricity that may be found in the part when it emerges from the machining operations. Note also in Fig. 11-B the out-of-line and slanting set screw hole.

Lack of concentricity (or eccentricity) as a problem is not confined necessarily to metal cutting or machining operations.

In manufacturing rubber or plastic insulated electrical wire by the mile, for instance, one of the problems at the insulation extrusion equipment is to maintain the centrality of the copper wire within its insulation coating. If the wire gets off center, leaving a thin section of insulation on one side and an unnecessarily thick layer opposite, the finished insulated wire will not withstand the voltage test required because of the lack of sufficient insulation on one side of the wire.

Unsatisfactory Hole and Shaft Conditions

In Fig. 8, several conditions which may appear in the bored or drilled holes were illustrated. In much the same manner shafts, bushings and all turned and cylindrical ground work may leave an operation as anything but a perfect geometric cylinder. The presumed cylinder may be tapered, barrel shaped, like an hour glass, or oval. See Fig. 12 for illustrations,

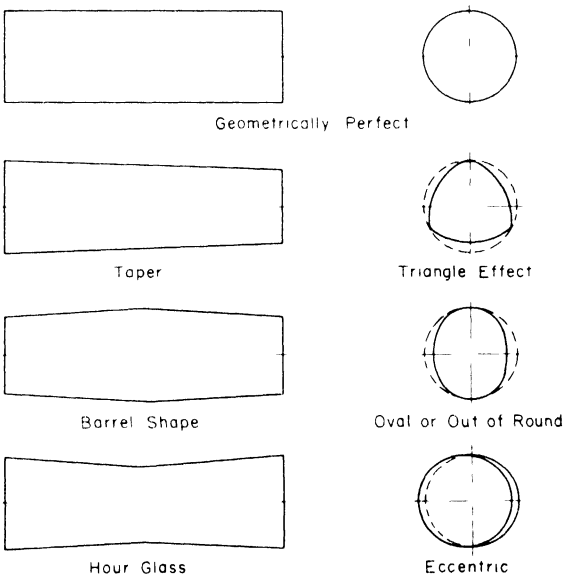


Fig. 12. Perfect cylinder and variations in the shape of a cylinder caused by improper grinding.

in exaggerated form, of these conditions. They may be imperceptible to the naked eye or ordinary measuring instruments but one of them, or some combination of them, exist on any piece that is turned or cylinder ground and can be discovered

where sufficiently fine, accurate measuring equipment is used.

The experienced shop inspector is especially alert to what he usually calls taper and out-of-round. In other words, he may not analyze the absolute condition in terms of hour glass effect, say, or ovality or eccentricity. Conversationally, the expressions taper and out-of-round cover all conditions. But he knows that, irrespective of the exact analysis of such a general condition or the specific term to be applied, it always exists to some degree after any turning, boring, or cylindrical grinding operation — internal or external, and that it makes trouble at assembly or causes wear, vibration or interference where it becomes excessive on component parts.

The "Triangle Effect"

A rather special condition, in the class of ovality or eccentricity yet unlike them, is the so-called "triangle effect" also illustrated in Fig. 12. The triangle effect is almost inevitable in centerless grinding operations. It frequently gets by an

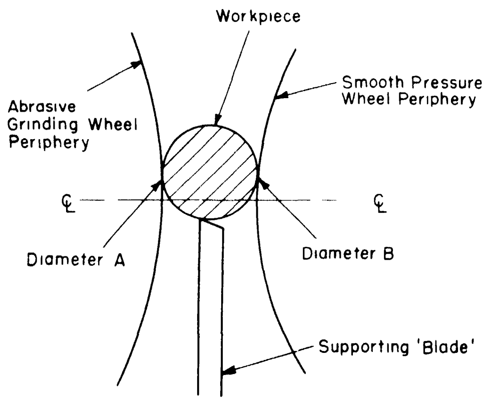


Fig. 13. Schematic diagram of centerless grinding operation.

inspector because special measuring setups are required to detect it. A shaft or cylindrical part is held in a centerless grinder in cutting position between the grinding wheel itself and a revolving guide or pressure wheel and a stationary guide blade or rail, as shown diagrammatically in Fig. 13. Unless, or even though, the guide wheel and guide blade are very carefully set, there is a momentary, yet continuous condition where the grinding wheel is cutting or reducing the

diameter of the workpiece on its side — at *A* in Fig. 13 — while, in effect, a larger diameter of the workpiece is momentarily rolling against the revolving guide wheel — diameter *B* in Fig. 13. The result is a tendency toward the triangle effect, if not the actual condition. The so-called "triangle effect," may result in six or nine points — two or three triangles may be set up in effect, or under certain grinding conditions five or even seven points may be present. The skilled operator or tool setter can so nearly obviate the triangle effect that it cannot be detected (practically), but it may appear at any minute because the grinder adjustments may vary a trifle from temperature changes, vibration and the like.

Unwanted Burrs and Fillets

When the draftsman shows a square edge or corner on the print as in the case of the simple step block shown in Fig. 14, part A, he expects it to be sharp, clean and square. Otherwise

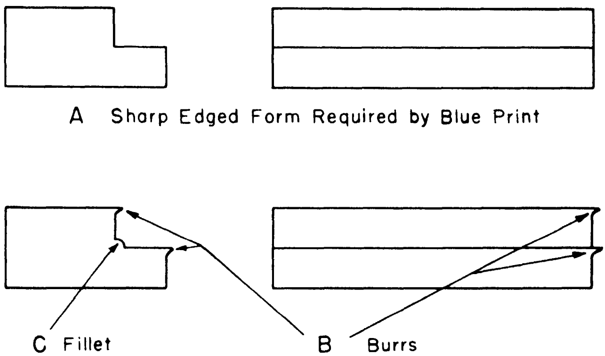


Fig. 14. Although blueprint calls for sharp corners, burrs and fillet may be produced by machining.

he would have put a note on the blueprint to "break all edges," (meaning to file, grind or emery belt a slight chamfer on an otherwise very sharp corner) or he would have provided for radii or definite bevels by means of notes and dimensions on the print.

At the machine, however, most usually a burr is formed as indicated at B in Fig. 14. Some of the metal is crowded or pushed out over the normal edge in the form of an overhanging lip, frequently razor sharp, by the cutting tool or grinding wheel. Burrs are persona non grata on manufactured parts.

A close relative of a burr is the fillet. Here is the case where the square sharp edge of the cutting tool or wheel becomes rounded off (or the machinist begins to withdraw the tool just at the corner), thus leaving a tiny bead of unwanted metal in the corner as shown at C in Fig. 14.

Experience with local conditions in his own shop will point out a number of similar product conditions to the inspector which are not specifically warned of on the blueprint but which nevertheless prevent conformance of the part to specifications. In the average factory the responsibility for detecting many of the troubles described and implied in the paragraphs above seems to gravitate to the inspector. For some reason, operators and tool setters direct so much attention and energy to maintaining dimensions and the requirements in specific blueprint notes — at the same time keeping an eye on the production quota — that they overlook other essentials that are also plainly pictured on the blueprint. The obvious is easily ignored.

Operation Sheets as Specifications

Many factories use shop orders, operation sheets, process records or similar devices for specifying the exact operations to be done and their order of accomplishment. Such a breakdown enables, among other things, a timing of each job and is an important element in production control, wage incentive rates and scrap reduction. An operation sheet also serves an educational purpose by directing new workers in the most economical way to proceed in manufacturing the product. The process record or an operation sheet is the official record of methods. Usually it travels with the production order to the job and is in turn accompanied by the required blueprints.

A typical commercial operation sheet is displayed in Fig. 15. This particular operation sheet applies to a part having a contour of the type outlined in Fig. 7. A glance at this operation sheet discloses its value to the inspector. In a preceding paragraph a preparation routine was suggested — certain orderly steps the inspector should adopt in securing information from the blueprint concerning the product he is about to inspect. One more step could well be added to that list: look for an operation sheet or a process record.

From this operation sheet, Fig. 15, the inspector can immediately pick conditions to be checked that he might not have

PART NUMBER BS - 28	.375" X .875" COLD ROLLED STEEL					
OPERATION	**TOOLS**	**MACHINE**	**MCH. NO.**	**SPEED**	**FEED**	**JIG OR FIXTURE**
CUT OFF TO 1.125 (1 at a time)	Abrasive Whl	Abrasive Cutter		Set	Hand	Clamp
GRIND (4) SIDES TO REMOVE BURRS	80 Gr. Blt.	Belt Grind	4	Set	Hand	
STRADDLE MILL TO 1.062 (14 pcs)	.375 X 4.000" side cutters	Miller	4	2-92	522' min	T-1765
FILE 4 EDGES-2 SIDES (to burr)	#6 File	Bench			Hand	
STRADDLE MILL SPRING SLOTS Top (17 Pcs.).250" wide File edge (2) before removing Reverse Straddle Mill Fixture Bottom (17 pcs) .250" Wide File edge (2) before removing	2-.250" Cut	Miller	4	2-92	.644 min	BS-25 Tl
GRIND ALL OVER (To Burr) Lines to run lengthwise	100 grit belt	Belt Grind			Hand	
MILL STEP (.062" X .313") 5 Pcs. File Burrs	.375" Side	Miller	29	105	.750 min	Mill Vise Parallel T-1765
DRILL 5 HOLES 4 Spring Holes .250" Deep 1 Contact Hole .375" Deep	.093" Drill .118" Drill	Drill Pr.	18	3-580	Hand	T- 1763
DEGREASE	Wire Basket	Degreaser			Hand	
TAP 4 SPRING HOLES	4/48 Tap	Drill Pr. w/Att.	17	1-480	Hand	Mach.Vise
TAP 1 HOLE	6/40 Tap	" " "	"	" "	"	" "
DEGREASE	Wire Basket	Degreaser			Hand	

Fig. 15. Typical operation sheet for a part similar to that in Fig. 7.

thought of if only the blueprint had been examined. It may be necessary for him to verify the stock size, (.375-inch x .875-inch cold rolled steel, as shown on the heading of the operation sheet). If by accident the operators have been furnished with stock too thin or too narrow, the parts they make may not "clean up," that is, finish to the required dimensions, in subsequent operations.

Observe on the operation sheet the burring and grinding operations specified to free the parts from burrs — items that did not appear at all on the blueprint. The inspector may find it necessary to verify all drill and tap sizes, making certain that those which the operators are using correspond to the operation sheet instructions and that both are consistent with the corresponding blueprint notes or that they will produce the size and kind of tapped hole the blueprint specifies.

Note, also, the sixth item on the operation sheet, Fig. 15, which specifies that belt grinding marks or lines are to run lengthwise of the piece, a condition probably essential to the ultimate appearance of the finished product in which the piece will be assembled.

Burring operations are specified in items 4, 5, and 6, for instance, so that the parts will fit accurately in the drill jig specified for item 8 (jig #T-1763) — another example of a factor not mentioned on the blueprint of the finished part.

The inspector is aided, too, when an operation sheet calls for the removal of burrs. If he were to measure the length of an unburred piece, for instance, he would get a false dimension — measuring not the correct length of the body of the piece but the false length produced by the overhanging burrs. Remember that a burr or edge overhang so slight as to be scarcely visible or tangible even to the fingers, can still cause an error of several tenths of a thousandth, if not a full thousandth, in the measurement secured. If no routine deburring operation is called for, an inspector must make sure to free the pieces he is measuring from burrs by filing or with emery cloth.

It should be clear, now, that an operation sheet or process record is essential information for the inspector. Many plants, however, do not have operation sheets. They depend on the native skill and "know-how" of the machinists or their supervision or upon word-of-mouth instruction, memory and tradition. Then, too, the manufacture of many products does not respond naturally to operation-sheet control. Foundries, plastic molding, wood working, punch and forming press shops, and wire, brass and paper mills, to name but a few of many places, may not rely on the specific operation sheet or process record.

When no official operation sheet prevails, an inspector must, of course, gain the equivalent information as rapidly as possible from experience, from observation and asking questions. He cannot know too much, too soon, about the unexpected effects of the process on a product he is assigned to inspect and judge. It might be wise for him, especially where he is new on a job, to write out, in effect, his own operation sheet.

Written Specifications

In many types of industry, such as rubber, plastics, paper, fabrics, wire and sheet metal, blueprints and operation sheets

may not be used much, if at all, as has been said. There may be a form of process record. More likely, however, a set of formal, written specifications are used — manufacturing specifications. Government procurement agencies, of course, make frequent use of specifications. In fact, nearly every article, staple or device required by Federal Government departments is covered by detailed specifications.

Specifications may occasionally be found where blueprints would be expected. This is especially true in the manufacture of more or less staple articles. A sample specification covering the purchase of ordinary wood screws is quoted below:

"Wood screws shall be furnished in three types; namely, flat, oval, or round head as particularly specified."

"Wood screws shall be made of steel or brass as particularly specified."

"The length of all screws shall be measured from the largest diameter of bearing surface of the head to the extreme end of the point measured parallel to the axis of the screw."

"The diameter shall be measured on the body of the screw under the head."

"Standard screws shall be furnished with gimlet points."

"Wood screws shall be furnished plain, uncoated, unless blued, nickel plated or other special finish is particularly specified."

Specifications are ordinarily so peculiar, particular, or unique in or to some class of industry that no extended discussion concerning them is possible here. The points to be emphasized are that specifications are used in industry and the inspector must be sure to know about them; in studying specifications, he must make sure of observing and remembering essential items in them.

Purchase Orders

Perhaps the most common industrial form of written specifications is the purchase order. In many instances the customer's purchase order, or a copy of it, is the only information the shop has from which to manufacture parts or products. As a simple example, a woodworking plant might receive a purchase order for "one thousand ¼-inch dowel-pin rods, birch, three feet long."

More frequently, however, the purchase order requires something more complex than pieces of hardwood dowel. It may refer to a catalogue part or number. It may be accompanied by a blueprint or a more explicit and voluminous set of written specifications.

The wording of a purchase order can be valuable to an inspector because, many times, all of the information appearing on it is not transmitted through to the shop or the information is interpreted in a manner satisfactory for manufacturing but not for inspection.

For example, an order is placed with a certain plant for a large quantity of compression springs to be used in foot-button automobile starter switches. This plant's sales and engineering departments had studied the customer's requirements at first hand, in addition to reading the customer's purchase order with its accompanying blueprint. Then the engineers drew up a blueprint of the spring for use on their own shop floor. The print indicated the wire size to be used, the temper of the wire, the number of turns and coils and their spacing or pitch, the diameter of the wound spring, the total length of the required spring, the type of ends, and a number of other mechanical details. In other words, the print gave the shop mechanics every whit of information they needed in order to make the springs exactly as ordered.

When the springs were presented for inspection, they could have been readily checked for dimension — wire size, coil diameter and pitch, and the like — and approved for shipment as being according to blueprint. In this case, however, the inspector was not fully satisfied. He wanted, correctly, to examine the springs from the viewpoint of the customer. Technical dimensional details were all right so far as they went, but he knew that performance, after all, was the thing that counted. What did the customer expect the springs to *do?* Examination of the purchase order brought to light a specification paragraph which the factory's engineers had not copied directly onto the blueprint. They felt that they had accurately translated this information for the shop in the form of wire size, coil diameter, pitch, etc. and that the springs, so made, would perform in accordance with the following paragraph.

"When compressed to 1-inch length, spring is to exert 11½ oz.-15 oz. pressure. Closed coil length — 15/64 inch. End coil must not close before spring is compressed to ½ inch."

This was the definite information the inspector needed in order to make a comprehensive test of the conformance of the springs ordered.

One point to be emphasized here is that an inspector should keep always in mind the function, the performance, of the product, part or detail whose conformance to a print or specifications he is measuring. In order to do so intelligently, he may need to seek more information than appears on the relatively bald specification of a blueprint.

Other Types of Specifications

Specifications appear on factory floors also in the forms of contracts, shop orders, letters, memoranda and sketches. A contract is a formal form, to put it that way, of a purchase order or letter. Usually the particular specifications included in a contract are quite detailed and complete. The contract form is used in place of a purchase order to cover unusual contingencies such as special delivery dates or penalties for delivery delays, to describe special customer acceptance procedures or details of payments. Where huge quantities of product are being purchased, extra manufacturing facility investments may be involved, many months may be needed to complete the order — these are some of the reasons a contract sometimes supersedes the ordinary purchase order.

As for sketches, verbal orders, memoranda and similar informal types of shop orders (which are nevertheless specifications) the inspector needs first to question the authority or official character of such instruments, as has been already intimated, and secondly to make sure he has all the information required to make a thorough inspection of the product.

In the larger organizations, seeking some of the sort of information described or implied up to this point is technically more a function and responsibility of the inspection department, itself, and not of the individual inspector. The latter cannot readily visit engineering, sales and purchasing departments, or the laboratories, nor can he travel to customers' plants to secure the detailed knowledge he needs. Nevertheless, local restrictions should not prevent his persisting in some manner. Continued, intelligent study in his own area will always help. He can and should, of course, approach his own supervision for additional needed information. The danger is that of familiarity; that he may take too much for granted; that he feels he knows all about the part or product he is inspecting. Remember, always, that the requirements may have been altered since the last time the particular part was

made. With catalogue items, regular production and staples especially, the inspector's error is usually that of presuming more knowledge than is actually possessed. Facts form sharper tools than opinions or assumptions. Don't be lazy; dig out all the information needed to make a comprehensive inspection.

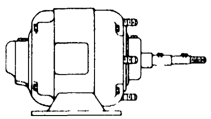
INSPECTION PLANNING

CAT. NO.
MODEL NO.
DRAWING NO. All GR. WORK CENTER 14 LOCATION Taylor St. SCRAP CLASS Copies OPER. NO. SHEET 1 OF 1
PART NAME motor MATERIAL SPEC. NO. PLANNED BY J. H. Cline
DATE 9-23-46 SUPER New
DATE 10-16-46 SUPER 9-23-46
DATE 1-27-47 SUPER 10-16-46
DATE SUPER
NUMBER

GAGES AND TOOLS
6" Scale
Eccentricity fixture
2" Paint brush
End play gage
Rivet hammer
Stamps
Stamp pad
Shoulder gage

SEQUENCE
Parallel
"M" dimension
Shoulder to face
Rabbet height
Rabbet diameter
End play
Visual
Assem. studs
Stamp
Oil

CHECK DRAWINGS & INSTRUCTIONS FOR ADDITIONAL INFORMATION.



Tag Rework pieces with FW2322 and return to Mfg. section.
Tag Review pieces with FW2321, send to review area.
Tag Condemned pieces with FW1136A or FF262A, send to scrap department.
Record rejects on Product Rejection Data sheet.

Received on bench from test.
Line up and wipe off excess oil.
Check model list against label, GLJ tag and nameplate.
Check outline for dimensional inspection.
Check requisition for any deviation from model list and for "X" number.
Place on face plate, install plugs in the two holes on the horizontal axis, check the parallel condition from base plane using height gage and last-word indicator max. out-of-parallel is .010".
Check "M" dimension to insure right base.
Gage shaft shoulder to rabbet face.
Scale max. rabbet height 1/8" with 1/2" clearance.
Gage end play.
Vernier customer's rabbet diameter.
Check shaft for true with last-word indicator.
Check customer face and rabbet for true.
Visual inspect for retainer screws, rabbet face to end of clamp bolt, burr on clamp bolt boss, condition of pulley end shaft seal, tightness of conduit box, "X" number, clamp bolts tight, washers under heads, cover screws, paint on rabbets, rubber bushings in flanges, customer's tapped holes, rabbet finish and finish.
Assembly studs in customer's holes.
Date stamp nameplate.
Tape key to shaft. Note. Do not place key in shaft.
Tie on "OK" tag.
Oil shaft and machined surfaces.
Stamp with acceptance stamp if OK.
On non-acceptable pieces

Fig. 16. Example of an inspection planning sheet which is used to guide the inspector.

Inspection Specifications

There is a growing tendency in many shops to issue detailed instruction sheets to inspection personnel. Such specifications, slanted to the needs of the inspection department, help materially to cover the sort of lapses implied in the preceding paragraph. They are valuable, also, as check lists, of a sort, preventing inspectors many times from forgetting essential inspection steps. An example of an inspection planning sheet is shown in Fig. 16.

CHAPTER 3

Tolerances and Allowances

Modern industry has developed on the basis of interchangeable manufacturing. Interchangeable manufacturing means the production of parts to such degree of accuracy as is necessary to permit the assembly and proper functioning of the parts without further machining or fitting, although the individual parts may have been made at different times or in different manufacturing plants. In other words, the parts are theoretically, at least, interchangeable.

Ideal interchangeable mating parts would be those without any kind of dimensional variation, that is, they would be exactly the size called for on the blue print or specification. In actual practice, however, there are factors which make it impossible to meet this ideal condition. Some of these factors are:

(1) The machines which are used to produce the parts have inherent inaccuracies built into them and therefore cannot produce perfect parts.

(2) In setting up the machine, that is, adjusting the tools used in the machine, the operator cannot make perfect settings.

(3) Variations in the properties of the material being machined introduce errors.

(4) The prohibitive cost of attempting to entirely overcome the first three factors favors making the parts as inaccurate as is tolerable, that is, just good enough to do their intended job and no better.

Limits of accuracy are needed, therefore, for the various parts and also for groups of assembled parts; then manufacturing and gaging equipment can be used to obtain and check the established limits.

Need for Basic Dimensions

A basic dimension is the theoretical or nominal size, which, for practical reasons, is only approximated; or, it is the dimension which would be obtained if perfection were possible and did not result in increased manufacturing costs. However, since perfection is impossible and also unnecessary, so far as the dimensions of machine parts are concerned, it is general practice to give a base or *basic dimension* and then indicate by supplementary "tolerance" dimensions just how much the actual dimension can vary from the basic without causing trouble; or, to put it another way, how much *inaccuracy* is allowable without causing a part to fit or function improperly.

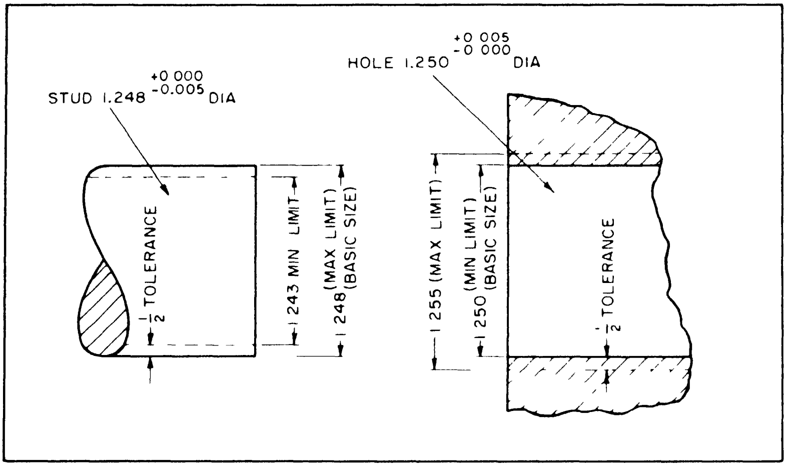


Fig. 1. Graphic illustration of the meaning of the terms limit and tolerance.

Anyone at all familiar with mechanical devices knows that there are wide variations in the accuracy required for different parts. Some, for example, might need to be within 0.001 or 0.002 inch, or less, of a given or basic size, whereas other parts might function perfectly if within, say, 0.010 to 0.020 inch of this basic dimension. To illustrate further, suppose that a hole (which is to receive a stud) requires a diameter of about 1.250 inch (see Fig. 1); but assume that the actual diameter may vary from this 1.250 inch size as much as 0.005 inch oversize without too much play between the hole and stud. In this case, 1.250 inch is the basic dimension or the dimension aimed at. In producing such holes, some might happen to have

a diameter of exactly 1.250 inch, whereas the diameters of other holes would be up to the maximum of 1.255 inch and yet serve equally well. Since, as a general rule, approximate dimensions are easier to obtain and maintain than very accurate ones, unnecessary accuracy is avoided unless it is obtained without extra cost or effort.

Why Tolerances are Specified

For these reasons, tolerances are applied to the dimensions of all manufactured parts. A tolerance indicates how much a part may deviate from its ideal or basic dimension and still function properly. A bearing, for example, may require a 1-inch diameter bore to accommodate a 1-inch diameter journal. To make the bearing exactly 1 inch would be impossible, and even if this could be done, the bearing would wear in actual use to a somewhat larger dimension. In the light of these facts, what tolerance should be applied to the 1-inch diameter bearing bore? Suppose that experience shows that the bearing has to be replaced when it has worn 0.005 inch oversize. Certainly, then, the tolerance would not be 0.005 inch since this would permit the manufacture of bearings which were, in effect, worn out before they were ever used. Should 0.004 inch be specified? If so, the bearings produced would range between 1.000 and 1.004 inches in diameter and those bearings which were 1.004 inch in diameter would have only 0.001 inch of wear life left (1.005 minus 1.004 = .001). Suppose that 0.001 inch is the tolerance which is finally decided upon, that is, the bearing can be made from 1.000 to 1.001-inch diameter. This tolerance would represent a compromise between two things; the desired life of the bearing and the cost of machining it to a tolerance of 0.001 inch. It is possible to machine the bearing to a closer tolerance, but it may be that it is more economical to hold the 0.001 inch tolerance and replace the bearing sooner when it is worn than to hold the closer tolerance. The tolerance decided upon, therefore, represents a compromise between the accuracy required for proper functioning and the ability to economically produce this accuracy.

Unilateral and Bilateral Tolerances

The term *unilateral tolerance* means that the total tolerance, as related to a basic dimension, is in *one* direction only, as

shown in Fig. 1. For example, if the basic dimension were 1 inch and a tolerance of 0.002 inch were expressed as 1.00 — 0.002, or as 1.00 + 0.002, these would be unilateral tolerances, since the total tolerance in each case is in one direction. On the contrary, if the tolerance were divided, so as to be partly plus and partly minus, it would be classed as *bilateral*, as shown in Fig. 1. Thus, $1.00\ {}^{+0.001}_{-0.001}$ is an example of bilateral tolerance, because the total tolerance of 0.002 is given in two directions — plus and minus. (See diagrams, Fig. 2.)

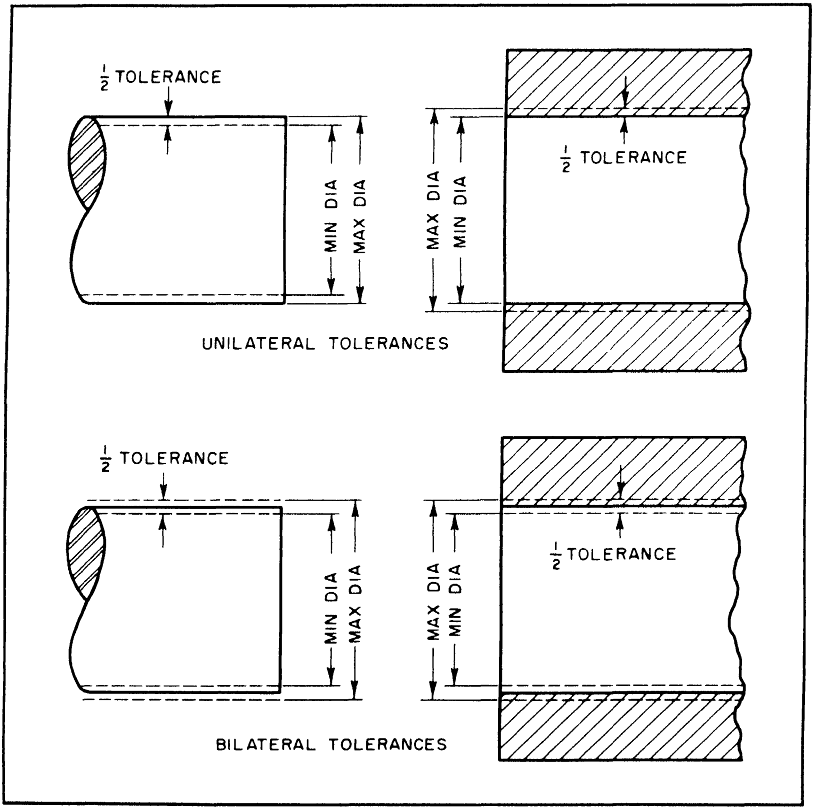


Fig. 2. Diagram illustrating unilateral and bilateral tolerances. Full lines show basic diameters, dotted lines allowable variations.

There are different ways of expressing tolerances or of giving allowable dimensions. These different methods should be understood in order to properly "read" or interpret the

dimensions on a drawing. When tolerances are unilateral, one of the three following methods should be used to express them:

(1) Specify limiting dimensions only as

Diameter of hole:	2.250, 2.252
Diameter of shaft:	2.249, 2.247

(2) One limiting size may be specified with its tolerances as

Diameter of hole:	2.250 + 0.002, − 0.000
Diameter of shaft:	2.249 + 0.000, − 0.002

(3) The nominal size may be specified for both parts, with a notation showing both allowance and tolerance, as

Diameter of hole:	2¼ + 0.002, − 0.000
Diameter of shaft:	2¼ − 0.001, − 0.003

Bilateral tolerances usually have plus and minus tolerances of equal amount. An example of the expression of bilateral tolerances follows:

$$2 \pm 0.001 \text{ or } 2 \begin{matrix} +\ 0.001 \\ -\ 0.001 \end{matrix}$$

Bilateral tolerances are not always divided equally as in the preceding example. To illustrate, if the total tolerance is 0.003 inch, it might be given as plus 0.001 and minus 0.002, in which case it would be written as follows:

$$2 \begin{matrix} +\ 0.001 \\ -\ 0.002 \end{matrix}$$

In general, if a greater tolerance is permissible in one direction than in the other, this may indicate that the tolerance should be unilateral instead of bilateral.

Positive and Negative Allowances

No mention has been made of the term "allowance." Let us consider the journal which is to run in the 1-inch diameter bearing, which can vary from 1 inch to 1.001 inch because of the tolerance of 0.001 inch. The journal also will have a tolerance applied to it. Assume for convenience that this tolerance is also 0.001 inch and that the shaft, therefore, can be made from 0.999 to 1.000 inch in diameter. If, in assembling the bearings and journals, it happens that a 1.000 inch diameter bearing and a 1.000 inch diameter shaft are picked up at

random, it would be found that if they were assembled, the journal will not turn properly in the bearing. A journal could be selected, say, one that is 0.9999 inch in diameter, and this would fit in the bearing. To eliminate the need for selecting mating bearings and journals by trial, it could be specified that no journal is to be made larger than 0.9999 inch. The result of such a specification would be that any journal chosen at random would be loose in the bearing by at least 0.0001 inch (1.000-inch bearing minus 0.9999-inch journal). This intentional looseness between mating parts is called the allowance. What determines the amount of this allowance? In the case of a bearing and journal, space must be provided for an oil film, otherwise proper lubrication cannot be attained. In the case of a shaft which is to be fitted into the hub of a pulley, a snug fit is desirable, therefore no allowance or even negative allowance may be provided. (Negative allowance instead of producing looseness results in interference between the metal of the mating parts and therefore requires the application of force to assemble the parts). The intended function of the assembly, therefore, determines the allowance or type of fit that should be used. Certain types of fit have been standardized and allowances and tolerances for these may be found in the American Standard for Tolerances, Allowances and Gages for metal fits.

As a further example of how allowance and tolerance are applied to metal parts, consider a shaft dimensioned 0.874 inch and a hole dimensioned 0.875 inch. This represents an allowance of 0.001 inch. (The same hole with a shaft dimensioned 0.876 inch also represents an allowance of 0.001 inch, but, since the shaft is larger than the hole, it is negative allowance). In manufacturing these parts the dimensions could not be produced exactly. For this reason allowable variations (tolerances) must be provided. If the tolerance required for each of the parts is 0.001 inch, then the shaft would be dimensioned 0.874 plus .000, minus .001 inch and the hole 0.875 plus .001, minus .000 inch. The greatest looseness between these mating parts would therefore be .003 inch and the greatest tightness would give a clearance of 0.001 inch.

CHAPTER 4

How Standards Aid the Inspector

In the industrial sense, standards are practices or limiting conditions, established or authorized as models for comparison. They may have become established as a result of the habits, usages and traditions of one or more manufacturers or they may have been developed to meet a specific need by a technical committee representing the various interested parties.

Many standards of manufacture are international in scope; others are national or industry wide. The American Standards Association, a federation of over 100 national technical and trade organizations serves as a clearing house for national standards. More than 1000 of these standards representing, in each case, a general agreement on the part of maker, seller and user groups as to the best current industrial practice have been approved by this association. Manufacturers use these national standards to facilitate production operations, lower production costs, and to eliminate controversies between buyer and seller. Then there are local standards, under which a single shop, or even a department within it, manufactures. A few standards are individual, a Stradivarius violin being a good example of the latter.

Emergency Standards

In addition to local standards which have been established carefully and deliberately, there are those which are born hastily in emergency. These seldom appear explicitly on blueprints or on specifications. Perhaps parts failed to fit together properly or wore out too rapidly. Or a customer complained, whereupon an executive rushed out into the shop with an order. After the tempest blew over the particular order was forgotten, at least by those in authority. It was intended only as a temporary decree anyway. But a routine had been started. Routine grows rapidly into habit and habit becomes tradition.

Standards set up under emergency conditions are not always the most satisfactory; nor are standards that have grown up like Topsy. The present-day tendency is to recognize that standards are as essential and useful as specifications. They are studied, analyzed, evaluated, revised and demonstrated, and made official, in writing.

Example of a Manufacturing Standard

An example of one of a group of standards for manufacture used by the Jones and Lamson Machine Company of Springfield, Vermont is given directly below.

Keyway Tolerances

Keyways must be in the center of the shaft within the following tolerances:

Shaft Diameters (inches)	0 to 1	1 to 2	2 to 3	3 to 4
Tolerance (inch)	.005	.010	.015	.020

Woodruff keys must be parallel with the shaft within .002 inch per inch of length.

Square keyways must be parallel with the shaft within .001 inch per inch of length and not out of parallel more than .005 inch in total length of keyway.

Depths of keyways must be according to drawing.

Long keyways in shafts that have sliding keys, such as cross feed screws, etc., must have a smooth finish on both sides. Maximum 15 microinches.

Bottom of these keyways may have feed marks but the marks must be even and free from chatter.

Standards Not Always Precise

Many standards can be precisely defined. The fact that a dimension appearing on a blueprint without tolerances is subject to the general shop tolerance of, say, $\pm$ .005 inch, as mentioned in a preceding section, is a precise standard of practice. Other standards are more illusory or more difficult to demonstrate. Personal opinion is involved. Is the gray enamel used on a product the same shade as it was a month ago? What precisely is meant, for example, by the statement that certain work is not up to our usual standard?

The practice in a shop may be to undercut all shoulders and bevel the edges of all bores in order to insure a close fit of mating parts. The fact that there is to be an undercut is a precise standard, but how much of an undercut or bevel may not be clearly defined.

Need of a Standard for Surface Finish

Very few discussions of shop standards take place without the subject of surface finish coming up. It is one of the most common wrangles in the machining trades. Is the finish fine enough or are the tool marks too deep, too coarse, too apparent, for a surface to be acceptable in appearance or for use? Should the machine be stopped and the tool sharpened or the wheel dressed? Is the operator making the cut too rapidly? Almost as soon as he appears on the factory floor the inspector bumps into problems of surface finish and right here is a good place to discuss a subject that is far from settled in industry. Only in recent years has it been possible for the engineer to write practical specifications for surface finish and for the shop to work to more definite standards.

Importance of Surface Finish

Surface finish is important not only as a matter of appearance or expert workmanship but, in the case of mating surfaces, has a positive and prolonged effect on product wear and usability. If two surfaces bearing against each other, such as a shaft turning in a bearing or a piston rod reciprocating in a gland, are too rough, unnecessary wear will take place. The turning shaft can act like a reamer and the piston rod like a broach. Where the roughness is excessive, the moving parts can heat up, bind and freeze. Excessive surface roughness on shafts and in bearings on, say, an electrical or motor driven household appliance requires more power — the appliance costs more in kilowatt hours to run. Research has shown, too, that where parts have fractured or ruptured under strain, the fracture itself frequently started at some surface irregularity and that the shaft with the rough surface fractured sooner — under less strain — than the shaft with the "super smooth" surface.

Poor surface finish many times neutralizes the effect of tolerances. Suppose a measurable surface finish of 100 micro-inches (100 micro-inches is really .0001 inch) appears on the surface of parts made to .0005-inch tolerances. As far as the close fitting together of mating parts is concerned, the operation has used up .0001 inch — one-fifth of the tolerance — in surface roughness. If at the same time the operator works to the high side of the tolerance (the usual condition), the presence of .0001-inch surface roughness may throw a high per-

centage of pieces actually into the oversize class, though, basically, the cut is at or just within the top tolerance.

If surface roughness on a lathe-turned piece is considered as, in reality, a very fine screw thread and if the shaft is assembled in a tight fitting hole, some of the sharp peaks of the "screw thread" will be bent or burnished down in the mere act of assembly. As the shaft revolves in the hole, the remaining peaks wear or burnish down very quickly. Soon a tight fitting assembly is loose. Automotive engineers recognize this condition and demand — advertise in fact — "superfinish" on many moving parts.

Factors which Affect Surface Finish

A machined surface appears exceedingly complex when viewed under a high powered microscope. What seems to be a smooth surface may contain several hundred thousand irregularities to the square inch. They take the form of rough cavities, pot holes, crevices, ridges, valleys and peaks. Some apparently smooth surfaces have the same appearance as a level, ploughed, field which is viewed from an airliner.

Surface roughness on a cylindrical piece turned in a lathe, with the tool or wheel travelling transversely, takes the general form of a screw thread or helix. The turning of the surface of a disc-shaped part held in a chuck, with the cutting tool moving steadily in from periphery to center, shows "phonograph record" lines. Surfaces of pieces from planer, shaper, milling machine and surface grinder compare with the straight ploughed field.

A common way of illustrating the elements of surface conditions is shown in Fig. 1.* The drawing shows irregularities in surface texture that are deviations from the geometrically ideal form. The several conditions indicated are defined as follows.

Roughness is defined as finely-spaced surface irregularities, usually in some sort of consistent pattern, produced by machining action from cutting edges, abrasives, burnishing or rolling. Each type of cutting tool and machining action leaves its own individual markings; each type of material — castings, ductile

* Taken from the A.S.A. bulletin B46.1-1947, Surface Roughness, Waviness and Lay, American Standards Association, 70 East 45th St., New York, N. Y.

materials, iron, brass, aluminum, etc., — also reacts differently to cutting tools and further develops a unique pattern.

Waviness is an irregular surface condition of greater spacing than roughness. It is not usually caused directly by the cutting edge but by work or machine deflections, vibration and the like. Irregularities that are geometrically similar may occur from warping or strains in the material. Waviness also usually shows a consistent pattern. Roughness is considered as superposed on waviness as may be seen in Fig. 1.

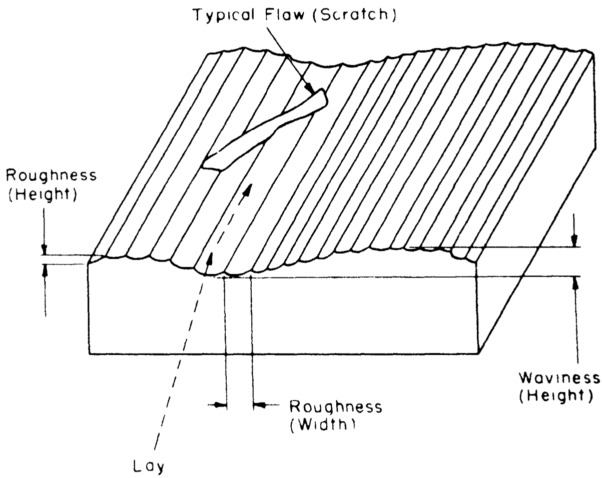


Fig. 1. Diagram showing some of the factors which affect surface finish.

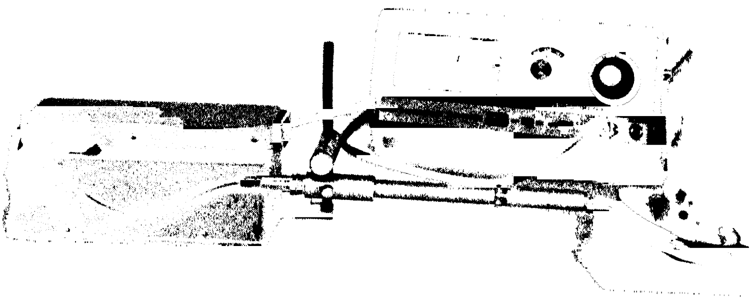
Flaws are scratches, digs, holes, peaks, ridges, cracks, or checking which occur at one place or at relatively infrequent intervals on the surface, usually without consistent pattern. The surface of a casting, for instance, may display waviness and flaws but not surface roughness as defined above. Machine the cast surface in some manner and the waviness and flaws may or may not be retained. The original waviness may be superseded by a new pattern and new flaws may be added. Regardless of these changes, there will have been superposed a degree and pattern of surface roughness.

One other definition should be offered here. *Lay* is the direction of the predominant surface pattern. In other words, the lay of surface roughness and waviness on a lathe turned cylindrical piece will be in the form of a helix. On a planed or

surface ground piece the lay will be parallel to one edge and perpendicular to the other or it may run at an angle, depending on how the piece was located for machining. The lay may be radial; it may spiral like the ridges on a phonograph record.

Measuring Surface Conditions

Surface roughness and waviness can be measured. Roughness may be felt with the finger nail. It may be seen with the naked eye. Then again the surface may seem smooth and polished to the eye or the finger nail but surface roughness still exists and it can be measured by optical and mechanical means.



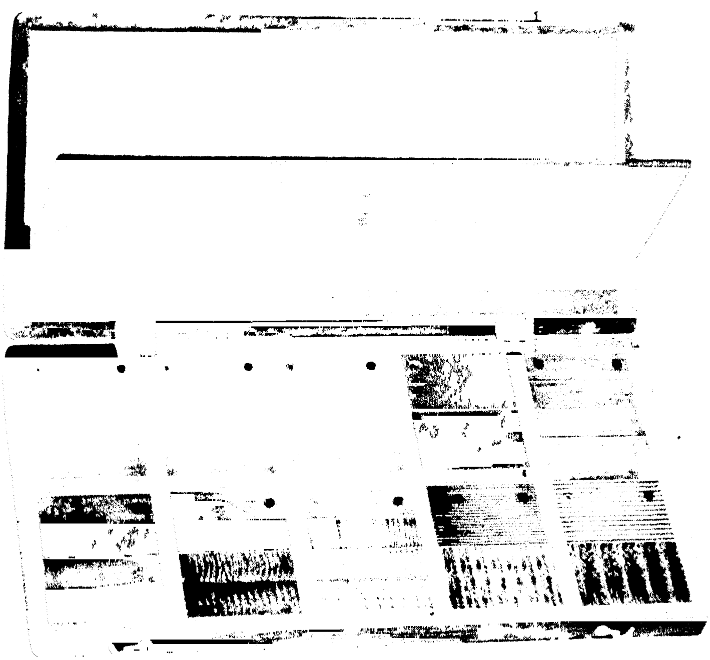
Courtesy of Industrial Metrology Div. The Bendix Corp.

Fig. 2. Measuring the surface condition of a work-piece with a commercial micro-inch surface apparatus.

Ordinarily waviness cannot be distinguished by eye or the finger. It must be detected by mechanical measurement — with an indicator or possibly an optical flat. Figure 1 shows that any pointed mechanical instrument for measuring roughness must have a stylus point finer than the width of the finely spaced irregularities while a similar instrument for measuring waviness could bear on the machined surface with a much broader point.

Surface roughness is measured (with instruments) in millionths of an inch — micro-inches. (Where the metric system is used, the micron — one thousandth of a millimeter — is the unit of surface measurement.) The width of surface roughness is measured in thousandths or tenths — as .0022 inch or .0008 inch, for example — and waviness is also measured in thousandths or tenths.

Figure 2 shows a part being checked for surface condition with the micro-inch finish of the part shown by the amplifier meter. The surface finish reading could also be recorded on a paper chart as shown in Fig. 24, Chapter 13.

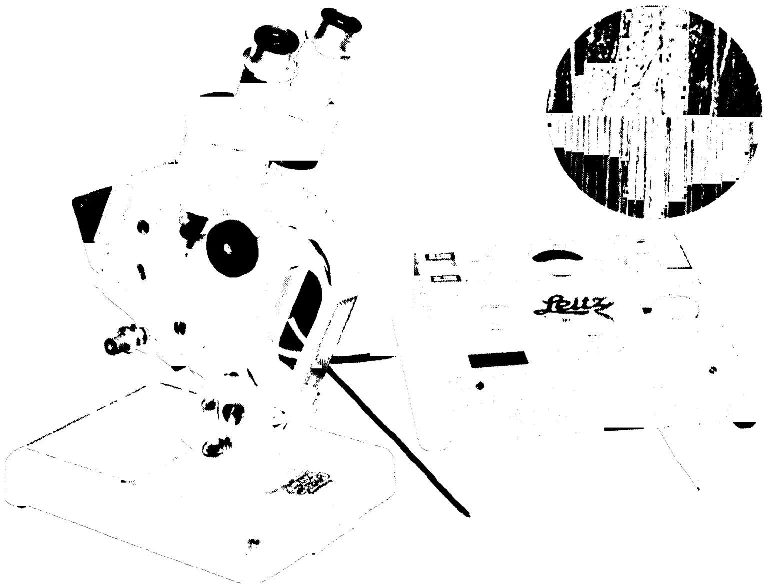


Courtesy of General Electric Co.

Fig. 3. Replica blocks for comparison with work-piece surface finish.

Surface roughness is also measured qualitatively by comparing the specimen surface with a standard surface whose actual roughnesses are known from precise measurements. This is done with the use of replica blocks or surface roughness comparators, so-called. One such commercial set is illustrated in Fig. 3.

Using roughness standards blocks or cylinders, the surface condition of the machined part may be compared to the replica block by eye, but the more accurate way is to scrape the surface of the workpiece with the finger nail and then scrape the finger nail across several of the comparator blocks until one test block is selected whose surface seems to compare closest with the machined part. The surface of the workpiece can then be established in micro-inches, within about 25 per cent accuracy, by reading the measured micro-inch legend for the comparator block selected.



Courtesy of George Scherr Co., Inc

Fig. 4. Stereoscopic microscope for comparing a work-piece with a standard of surface finish. Insert shows work-piece and standard surface finishes as viewed.

In Fig. 4 is shown a stereoscopic comparison microscope which permits three-dimensional comparison of a master roughness specimen with the finish of the work. Such a comparison is shown in the insert at the upper right in Fig. 4. The optical system in this microscope is such that when the standard and the work are viewed alongside of each other,

the resulting image produced in the eye pieces is without any demarcation line between the two.

Where a factory is equipped with accurate micro-inch surface measuring apparatus and where reasonable success is obtained in controlling surface finishes at the machining operations, the engineering department and its draftsmen symbolize the degree and direction of allowable surface roughness with a combination of symbols like that shown in **Fig. 5.** (Refer also again to Fig. 5, Chapter 2 and the accompanying text.)

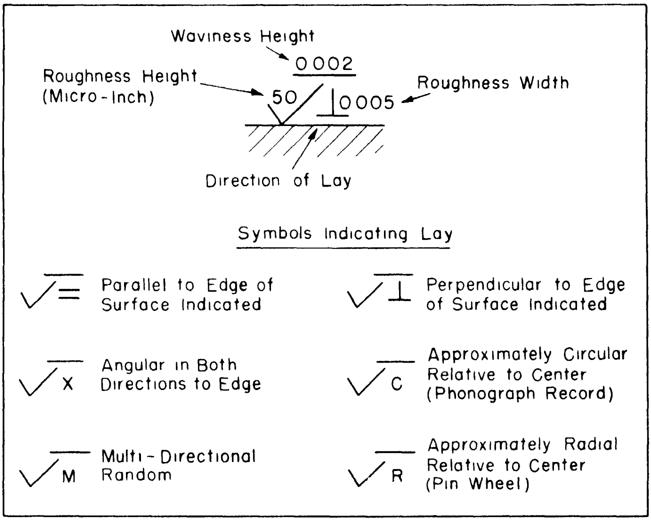


Fig. 5. Symbols used to designate surface finish.

These symbols on a drawing not only indicate to the machinist the amount of surface roughness desired but also anticipate the position of the pieces in his machine or the sort of pattern the machine is liable to produce. Part of the inspector's job in judging conformance of such parts, of course, is to determine how closely the dimensional degrees of roughness and waviness have been obtained and also that the direction of roughness conforms. This he can do with considerable precision if he has the use of mechanical or optical surface measuring apparatus. If he is using comparator or replica blocks he must reach a decision regarding conformance with his finger nail and eye.

Where only the symbols *f* and *ff* appear on drawings, as in Fig. 5, Chapter 2, or where the engineer issues no specific information in connection with surface conditions, another type of inspection problem appears. A great many shops have no surface condition measuring apparatus or methods at all. In other factories, apparatus may have been installed and surface specifications issued, but solely for use in an individual department or on a limited class of parts. Either way, inspectors in many departments find themselves faced with decisions over the quality of machined surfaces with no definitely official standards established or apparatus available for measurement.

Establishing Comparison Specimens for Inspection Reference

A natural and logical solution to this problem is to secure a supply of parts previously machined in the particular area and examine them. The inspector can, for instance, sort and catalogue the parts by eye according to surface finish (his opinions of surface finish), placing the poorest or coarsest specimens at his left hand, in a manner of speaking, and the best at his right, filling in between with a sort of graduated scale of specimen surface finishes.

By such procedure, the inspector will find himself able to make a more practical, comprehensive and accurate decision on a standard of surface finish than by a hurried, random selection of representative components. The eye should perhaps be supplemented by finger nail scratching across the surfaces of the specimens when lined up.

Having built up an orderly demonstration of surfaces, from the worst to best ordinarily available, the inspector will find that others in the area (including perhaps his own supervision and representatives from engineering as well as production people) can then more sensibly express opinions on desired or obtainable surface finishes. Within the time limit or facilities that may be available, the sort of "committee" action implied will be found valuable. Lacking definite surface specifications it is better to attempt a standard from agreement of all concerned than to establish what might turn out to be only a random, arbitrary standard.

With one or two specimens earmarked as standards for surface finish, the inspector can then proceed to compare and judge surface conditions by eye or finger nail, using the specimens as if they were registered replica blocks.

Economics of Surface Finish

Whether a surface finish standard is determined by an engineer, a committee, or from the more or less arbitrary opinion of an individual — whether it is to be measured by accurate instrumentation or by eye and finger nail comparison — the cost of securing and maintaining such a degree of finish throughout continuous production should be kept prominently in mind. It is perfectly natural to set the sights high when it comes to establishing a standard for surfaces. But the extra fine, smooth surface may not be worth it.

Better surfaces can be produced by slowing down the machine, perhaps, or the rate of tool feed or carriage speed. The more frequently the machine is stopped in order to sharpen the tool, the finer the surfaces secured. Changing from a coarser grit grinding wheel to a finer grit wheel will give a better surface, but fine wheels cut metal away much more slowly than coarse wheels. Honing a hole will leave a very smooth surface but it is a much slower process than broaching, boring, reaming or drilling. Often, superior finishes can be secured only by supplementary operations such as fine filing, polishing with emery cloth, lapping, honing, or buffing.

All of these may mean slower production, less total quantity at the end of a day, and a consequently higher cost per produced unit. The value of a finer surface must always be stacked up against the cost of getting that surface. Ball bearings supply a good example. The inner ball races, and the balls themselves, should be superlatively smooth. But the outer surfaces that are to be pressed into housings or over shafts need no such care or cost. Nor do the housings and shafts themselves require the highest type of finish.

Personal Standards of Surface Finish

The idea just discussed should be reemphasized. The person who is new to industrial inspection will instinctively look for, and wish for, better surface finish and appearance and just as instinctively reject work that is inferior in respect to surface appearance. The production operator naturally reacts to the rejections by trying to produce better surface finish but in so doing may reduce his production and to that degree increase the cost of the parts and the products. Personal "ideals" of surface finish may not be commercially feasible or commercially necessary.

Even the experienced inspector may keep the pressure on production unnecessarily for improved surface conditions. On the other hand, his familiarity with the job may cause him gradually to neglect surface finish and allow a decline in surface standards to the point of shoddiness. Surface finish has much to do with a product's reputation for expert workmanship, or the lack of it. The answer. of course, is to have suitable standards, review them frequently, and use them to compare current work with.

Then, there is the situation where the inspector is faced with the question of surface finish and is at the same time utterly bereft of surface measuring equipment, replica blocks or even homemade standards for comparison. Frequently, too, there is not even the semblance of specifications to guide him. He is suddenly handed a specimen of machine work. The surface — is it passable or not? An immediate decision is demanded.

Experience as a Guide

About the only way to forestall this sort of dilemma is to gain experience as rapidly as possible. Forewarned is forearmed. The new inspector can be observing, absorbing, the general grade and type of surface finish and appearance while he is receiving instructions concerning the routine of his new job; his eyes can be busy from the first minute he steps into the new department. In other words, the unwarned and inexperienced inspector becomes so intent on the instrumentation, mechanics, paper work and other particulars of the new task, if not overwhelmed by them, that he readily forgets or neglects the constantly important inspection items of appearance, of surface finish, until they are brought up abruptly to him for decision.

In situations where a hurried and more or less arbitrary decision has actually been made under pressure, the inspector might try what is frequently an amusing experiment. The suggestion about to be offered applies especially where the subject of surface finish, or any other visual standard for that matter, is the cause of frequent or regular disagreements. Suppose a standard of surface finish, based on visual opinion, has been adopted on a certain day, perhaps after a bit of discussion and argument. The record of the decision is a selected specimen of work. Suppose then the inspector stores this standard piece in a drawer or locker for several days or longer. When an exactly

similar wrangle occurs again, as it frequently will, he brings out the standard piece.

Almost invariably, it will be found that the standard of workmanship being argued over now varies from the standard so solemnly adopted a few days or a week past. It may be that the production people have urged a softening of the standard. Many times the inspector finds himself unconsciously insisting on a higher standard than he had chosen the last time. Bringing forth the sample work piece whose appearance everyone had sworn to follow shows quickly and amusingly how readily standards change, even over night, and how readily opinion can be biased by circumstances, especially those potentially unfavorable.

Separating Good Work from Bad

The main difficulty in establishing a standard usually lies in setting the line of demarcation between good and bad work, between acceptable and rejectable units. The transition from good to bad is seldom abrupt; we practically never have the situation in manufacturing comparable to people on one side of the tracks sharply differentiated from the social elements on the other side by a boundary as rigid as a railroad line.

An experiment made in a psychology laboratory supplies an illustration of the difficulty. The psychologist had rigged a caged-in platform for a rat. By turning a valve he could direct a jet of compressed air at the rat which would make the creature jump. In front of the rat were two white cards as barriers. On one card the psychologist had drawn a circle and on the other an ellipse. If the rat, impelled by the jet of air, jumped against the card with the circle on it, the barrier would fall down and disclose a supply of food. If however the rat leaped toward the card with the ellipse on it, he bumped his nose because that barrier was firmly fixed. After very few trials with the compressed air the rodent learned to jump toward the circle rather than the ellipse even though the experimenter interchanged the position of the two cards.

The psychologist then erased and redrew the ellipse so that it was less egg shaped and more nearly a circle. But the rat could tell the difference. Again the ellipse was redrawn more nearly circular. The cards were interchanged.

The experiment was continued to a point where the ellipse so closely resembled the circle the rat was unable to distin-

guish between them. Yet he was impelled by the merciless air jet to jump. He was forced to make up his mind how to avoid bumping his nose. But the ellipse and the circle looked so much alike he simply could not decide. The creature's solution of the completely frustrating situation was to roll over on his back, curl up his toes and sink into a coma.

Setting Up a Standard

One systematic solution of the standards quandary is suggested in the following procedure. In looking over groups of work there can be found examples that are definitely acceptable; also unquestionably rejectable units. Samples of the acceptable group can be classified by degree, or graduated in an order from wholly satisfactory to the worst possible degree that would still be accepted. In like manner, rejects can be graded upward by steps to the best appearing units that would still be rejectable. By looking at the work and the matter of standards from these two divergent angles the boundary between good and bad work, many times, stands out more sharply. If the "worst acceptable-best rejectable" procedure is used, it has been found from experience that the standard for workmanship is better based on the "worst acceptable" classification, on the theory that should the standard weaken or depreciate, consciously or unconsciously, the grade of work still accepted is not so poor as it would be where "best rejectable" marked the line and the quality of work slipped lower.

Where the quality of work is considerably a matter of opinion, the inspector can set up mentally a sort of numerical scale to help him. Suppose it is a matter of stamping a model or serial number on a nameplate or directly on the frame of the equipment. The inspector establishes (mentally) No. 5 as the standard, professional looking job. The letters and digits in such a legend are evenly spaced in a straight line and stamped sharp to a uniform depth. The No. 4 work is not quite so good and a No. 3 label contains almost an excess of errors. And so on down the mental scale. Letters and digits in the No. 2 class would begin to reel up and down hill; they would be unevenly spaced and illegible to the extent the stamps are dull; while a No. 1 job would not get by a drunken man. By "zoning" appearances in some such fashion, the inspector accepts No. 5 and No. 4 work, issues a warning when it slips off to No. 3 quality, and sharply rejects No. 2 and No. 1

grades. He has established a system much more consistent than independent spot judgment. In a short while, production personnel get on to the system and take to lettering in the assured No. 4 and No. 5 zones.

Demonstrating Standards of Workmanship

Bernard Baruch once remarked that the ability and facility to express an idea is almost as important as the idea itself. Originality, ingenuity, vision, aggressiveness and persistence are just as valuable in inspection as in any other field. Perhaps in no other branch of inspection work itself do some of the qualities just mentioned appear to better advantage than in selecting, proposing and illustrating standards. A decision is always necessary. It is better based on careful, unbiased study and analysis, and the courage of convictions always helps.

Where standards can be reduced to figures or dimensions, demonstrating them becomes easier. Surface finish, for instance, can be expressed in microinches and so measured by an instrument. Allowable taper or out-of-round may be limited to half the tolerance. But there are other conditions, especially of appearance, for which scientific measuring apparatus has yet to be devised. The sample piece has already been discussed, a sample that is "worst acceptable," if that procedure is adopted. One trouble with the single piece or specimen used to demonstrate a certain standard is that one gets used to it — so accustomed to it, that its message is readily ignored. The sample piece becomes dust coated, dirty, perhaps finger marked and greasy. Or it rusts and tarnishes. Where samples are used to demonstrate standards they should be kept clean and fresh. It is a good thing to renew the specimen every month or so.

Use of Standards Boards

So-called standards boards are excellent means for illustrating standards. An example is shown in Fig. 6. In this particular case, specimens were selected, generally in pairs, illustrating passable and rejectable degrees of each of the several types of defects potential in the operation.

Where a standard is to be illustrated by identifying or mounting specimens, it has been found, too, that a selection of three specimens offers the quickest and most accurate decision. One specimen, while it contains some degree of the defectiveness in question, is selected because it is nevertheless commer-

cially satisfactory. Another specimen marks a completely rejectable degree of the defect. Then a third, the borderline specimen, is very carefully agreed on. This shows a degree of

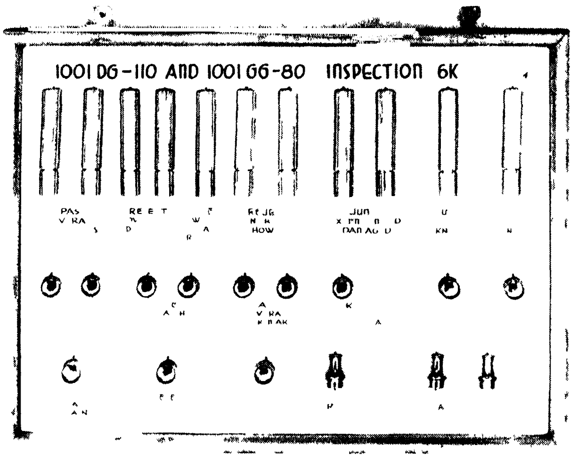


Fig. 6. One type of standards board which shows various acceptable and unacceptable conditions for inspector's reference.

the defectiveness under question such that if it were discarded as rejectable there would be little or no argument, or if it were found in the acceptable work there would be likewise no complaint. Perhaps the diagram of Fig. 7 makes this conception a little more graphic.

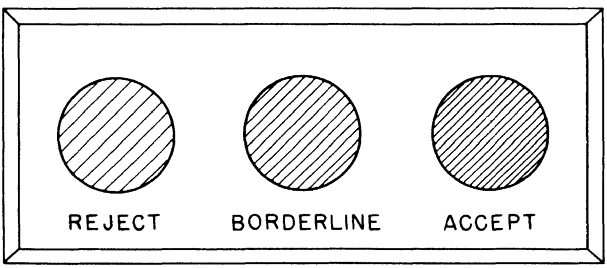


Fig. 7. Schematic arrangement of a three-piece sample board.

The careful arrangement of a three-piece sample board seems to permit a faster and more accurate decision. If a sample of subsequent work is held up beside the three piece

display of degrees of defectiveness, the classification of the work piece as either definitely rejectable or satisfactory seems to show more readily than where the work is compared to, say, a single acceptable sample or even to the paired, rejectable-acceptable samples.

The standards board idea is limited in practice to smaller units. Large forgings, stampings or castings, rod or sheet, or any sort of work piece larger than your hand, would ordinarily be too unwieldy for display, although sometimes sample boards are made up of small sections cut from the big pieces, the samples containing the sort of defectiveness occurring in the manufacturing operations.

The principles of selecting and demonstrating standards are not confined of course to surface finish. They may be applied to almost any inspection situation that cannot be solved by instrumentation. Another bone of contention common to manufacturing is the subject of burrs. Wherever metal is cut, ground, formed, punched or sheared, burrs are likely to form and a burred edge of any sort is troublesome at subsequent operations or on a completed product. Deburring means extra operations and added cost. On many occasions a slight degree of burr may not be insufferably objectionable. So, again, the inspector is frequently faced with the necessity of saying how much burr can be allowed, keeping in mind always the added cost of preventing, eliminating or removing objectionable burrs. Essentially then, the problem is no different than surface finish.

Standards for Various Finished Surfaces

Standards usually have to be established to prevent objectionable variations in the type of finish on painted, varnished and enameled surfaces as well as for variations in color from batch to batch. Nickel and chrome plated surfaces present very special problems along with their close relatives, polishing and buffing. The list is long and embraces virtually every type of industry — leather, plastic and textile surfaces; bubbles and flaws in glass; tool and chuck marks, chatter marks; roll and die marks, rubs and burnishes, on rod and sheet stock; wrinkles, pits, scratches and nicks; wear of engraving dies; pits, blow holes and shrinks on castings. The test or standard may also include such items as softness, brittleness, uniform penetration, flexibility, ring or tone, taste or odor.

Figure 8 illustrates an inspection test on spotlight types of electric light bulbs. At an early step in manufacture the interiors of the bulbs are "silvered" to form internal reflectors. If the reflecting metal is coated on too thickly, extra and unnecessary manufacturing cost is added at the production of each bulb both from the extra time taken to coat each bulb and also from the extra materials used. On the other hand, if the coating is too skimpy, light can shine through the reflector thus reducing noticeably the effectiveness of the lamp as a spotlight. The inspection standard set is based on the number

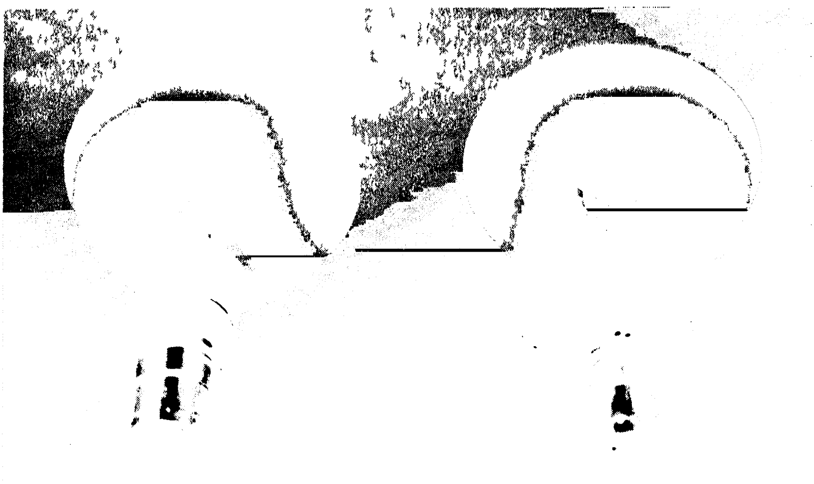


Fig. 8. Inspection samples Lamp A is "worst acceptable"; lamp R is a reject

and size of "pinholes" discernible from strong light shining through the reflecting surface. The lamp A in Fig. 8 is "worst acceptable" while the lamp B illustrates a reject.

Judging Color

Questions of color, shade, sheen or dullness of paint or enamel are frequent sources of dispute in factories as are the appearance of nickel, chrome and other electroplated finishes. In other industries there is often to be settled the question of similarity or difference in color or shade of goods coming from separate batches or dye mixes. Some people are the opposite of color blind; their eyes are quite sensitive to slight differences in shade. From experience and native ability they become

quite expert in their judgments of color. For the ordinary mortal, however, a couple of simple rules may lead to more accurate, consistent and dispassionate decisions.

In judging color, sheen or drabness, the matter of light is important. If a sample from a painted, dyed or plated batch is decided on as a standard, then subsequent test specimens should be viewed under exactly the same amount of light as the standard. A piece first viewed under a fifty watt lamp can look different under two hundred watt power or under fluorescent light. Window light may give it another appearance. The sample piece should be held each time at the same angle and at the same distance from the same power light as the standard specimen.

Because of oxidization, chemical action within pigments or plating, or the accumulation of films of dust or moisture, the appearance of a standard specimen will change in time. Usually, at least, the color or sheen becomes duller. Hence, where painted, enameled, dyed or plated surfaces are to be judged, the standard specimen should be renewed frequently.

Artificial aids help at times. The familiar ghastly beam cast by a mercury arc lamp is especially helpful in analyzing the condition of a polished, buffed or plated surface, although some inspectors swear by "daylight through a north window at mid-morning of a cloudless day." A high powered glass aids decisions concerning dullness. The system is a little like taking a blood count. By roughly counting, in the field of a microscope, the minute scratches, pits and irregularities that show on a "lively" surface and then making a similar rough count on a duller surface it will be found that the count of scratches etc. per unit of dull surface is much higher than for a lively surface. The microscope count can be established as a standard, as a method of establishing the line between dull and satisfactory finishes.

Standards Applied to Phases of Manufacturing Other Than Appearance

Where — as in America — so many products are mass produced, local, national and industry-wide standards have had to be adopted for a great many items in order to prevent confusion, duplication, and unnecessary manufacturing and assembly losses. The more standardization of certain types of parts we have, the more readily, for instance, service and

repairs can be offered on such products as automobiles, vacuum cleaners and plumbing fixtures. The nation-wide job of standardizing many common products is far from complete but new standards are steadily being added and old standards are being improved.*

Screws, nuts and bolts offer an everyday example of standardization. For instance you can find in most mechanics' handbooks the American Standard for No. 10 round head wood screws. A table in the handbook will indicate the prescribed diameter of the head, the width of the slot, the diameter of the screw under the head, etc. Certainly, the inspector should have access to one of the standard mechanical handbooks and study it enough to know where to find information pertinent to the products manufactured in his own shop.

As an example of handbook data on a type of established standard appears in the table below. This is presented merely to substantiate the suggestion that for many occasions, where some standard is under dispute in the inspector's shop, the best available answer may be found in a handbook.

Snug-fit Tolerances and Allowances — American Standard†

Closest fit which can be assembled by hand. It should be used where moving parts are not intended to move freely under load.

Diameters	Tolerances				Min.	Max.
	Hole+	Hole—	Shaft+	Shaft—	Allowance	Allowance
¼	0.0004	0.0000	0.0000	0.0003	0.0000	0.0007
½	0.0005	0.0000	0.0000	0.0003	0.0000	0.0008
¾	0.0005	0.0000	0.0000	0.0004	0.0000	0.0009
1	0.0006	0.0000	0.0000	0.0004	0.0000	0.0010
1¼	0.0006	0.0000	0.0000	0.0004	0.0000	0.0010
1½	0.0007	0.0000	0.0000	0.0005	0.0000	0.0012
2	0.0008	0.0000	0.0000	0.0005	0.0000	0.0013
2½	0.0008	0.0000	0.0000	0.0005	0.0000	0.0013
3	0.0009	0.0000	0.0000	0.0006	0.0000	0.0015
4	0.0010	0.0000	0.0000	0.0006	0.0000	0.0016

† Taken from *Machinery's Handbook*, 14th Edition, The Industrial Press.

Allowable Taper, Out-of-round or Eccentricity

Mention has already been made of standards required for allowable taper, out-of-round or eccentricity. It is just about impossible to manufacture parts without some degree of these digressions from the perfect geometrical shape. In fact it is

* The progressive inspector would do well to communicate with the American Standards Association, 70 East 45th St., New York City, and secure the list or catalogue of publications the Association issues describing the present day status of standardization in many products.

usually unnecessary and uneconomic to try to eliminate them entirely. Hence, standards for allowable taper, out-of-round or eccentricity should be established in every shop and, where necessary, for various individual parts. If the type of machined piece can give trouble at assembly or in shortened running life of some product because of one of these digressions, it is better to have the engineering allowance for it shown directly and concisely on the blue print.

But where the inspector is unable to secure any ruling as to the amount of taper, out-of-round or eccentricity allowed on acceptable components, he can frequently safely establish the rule that this amount may range up to half the published tolerance for the particular dimension. Some plants have a rule that these digressions may equal but not exceed a half-thousandth on any dimension whose tolerance spread is a thousandth or greater. A rule of this nature covers the evidently ridiculous situation where the tolerance allowed is perhaps — .010 inch and taper, ovality or eccentricity of .005 inch (following the half-the-tolerance rule) would be evident even to the naked eye.

Interpreting Blueprint Tolerances and Limits

Tolerances on blue prints are, of course, definite, published specifications but there are occasions in many shops where a little escape from them as rigid boundaries is condoned. Where such a policy prevails, the interpretation of tolerances calls for a shop "standard." Suppose the print calls for .435 inch $\pm$ .001 inch. Will this mean that a piece which measures .4361 inch — only .0001 inch oversize — will be rejected? In some shops the answer is firmly yes. There, the operator would do well to manufacture to a .4359 inch upper limit. In other shops some digression even beyond the tolerance limit is permitted. All right then, if so, what is the line? If .4361 inch is permitted, why not .4362 inch or .4363 inch? Or even .4365 inch? If the local practice is to condone some indefinite digression from published tolerances and if the inspector simply cannot get those in authority to establish a "standard" for such digressions, he will be forced to set his own standard. In the case mentioned above he might set, for example, his own rule that any work digressing beyond .4362 inch will be rejected, or, using the half the tolerance rule, he would accept up to .4365 inch but sharply reject anything larger.

If the situation implied above seem illogical, how many human compromises are purely logical?

Background Knowledge Helpful to Inspector

To a very considerable extent, standards cannot be intelligently established without some knowledge of how and where the part, subassembly or material is going to be used. One of the best lessons for a floor inspector is a few hours work as an assembly hand, using the parts he customarily inspects. Usually, where the workers and inspectors in a factory department have only an obscure idea of what will happen to the parts after they leave their hands, the standards of workmanship are established at one extreme or the other — either too severe or too slack. This is apt to be true where the manufacturer is "subcontracting" work which is shipped to another plant, parts that disappear into some product the other fellow half way across the continent is making and marketing.

In this regard the inspector should be objective and practical. An assembly operator transferred to a parts department as an inspector will at first, consciously or unconsciously, try to tighten up the standards, inadvertently interrupting or slowing down production and increasing costs. When an inspector's mind fastens on standards his primary reaction is to demand higher, better, tighter standards. From the thoroughly practical point of view, however, he should perhaps deliberately reverse himself and consider the possibility of existing standards being unnecessarily severe. If he will counter a natural tendency for perfection with an open-minded analysis of what the situation really demands, he will usually reach not only a balanced conclusion but probably a more correct and practical opinion.

In one department of a factory making small, portable, pump-like machines for compressing and straining liquids, short lengths of pipe were cut off and threaded. The work was done in lots of several hundred at a time as the stock inventories required replenishing. One length of pipe was used inside the machine where it was concealed from view. Another of the lengths of pipe appeared on the outside of the apparatus to be used purely as a handle to carry the portable pump from place to place.

The floor inspector rejected lots of the internal, concealed

pipe, objecting to chuck and tool marks on the surface, but overlooked the burr set up in the mouth of each piece of pipe when it was cut off. Inconsistently, when the same machine made a lot of the very nearly similar pipe lengths that would be assembled for handles, he paid no attention to objectionable external tool marks but insisted that bore burrs be carefully reamed out — in this case by hand. In other words he had the essential inspection standards completely reversed. The surfaces of the pipe lengths for handles should have been smooth and of good appearance; the bores of the handle pieces could have been plugged solid with burrs and chips since no liquid would flow through them. On the other hand, all sorts of surface tool marks on the internal pipes did no harm (provided the pipe lengths were not actually weakened) while the bore burrs gave a great deal of trouble in the field.

Standards Should be Consistent

If the situation just described seems somewhat improbable, only a little experience at inspection on almost any shop floor will bring to light many examples that are comparable, if not more ridiculous. One lesson can be learned here, however. Standards should be consistent. It might have been wiser in the case of the compressor pipe nipples to have required the same general standards for external appearance and bore burrs whether the pieces were to be used to conduct sludge or as handles. The matter of habit should be considered. To let word out on a shop floor that type A pieces can be run off without regard to quality but that great care must be used on the considerably similar pieces of type B, because the latter are to be used for certain special purposes, creates a sort of confusion. The operators get used to slashing out type A pieces and the slack habits established carry over inevitably into the manufacture of type B pieces. It is like "company" table manners. If we allow slurping coffee from the saucer at home we shall be awkward and unnatural about holding the coffee cup by its handle and properly curling the little finger when we go to dinner in polite society. And probably unconsciously make a slurping noise!

The more uniform and consistent, but practical, manufacturing standards can be across the board, the better the overall grade of workmanship and, frankly, the steadier and higher the production.

An example of the good effect of an inspector's knowing something about the use of a product occurred in a factory manufacturing textile machinery. Certain long rails or beds on spinning frames were being machined. Machinists carefully trained through apprenticeship and years of work felt, rightfully, that the rails displayed expert workmanship. From the point of view of a machinist they did — square corners, long surfaces smartly machined free from waves, chatter marks and blemishes. The inspector, however, nosed around the test floor where the machines were tried out under textile mill conditions. He noticed that the fine threads being spun and spooled snagged every so often, snarled, knotted and broke, as they happened to dip and touch the expertly machined rails. Every time this happened the spinning machine operator had to clear out the snarls, lint and slubs formed and tie a knot to start the spooling again at that station. The trouble was cured by breaking the sharp edges of the rails and by literally buffing them with a portable polishing wheel.

The inspector should continually keep looking at the products going by him with the eyes of the customer. Considering sensibly the price, competitive standing, and use of the products, would he buy them without grumbling over them? Is the workmanship as good as it was three months ago? From time to time you buy a certain brand of canned corn, hack saw blades or socks basically because their quality is uniform and consistent. Part of an inspector's responsibility is to secure, through his influence on the situation, a desirable uniformity. He must not sanctimoniously tighten up on standards one day and carelessly ignore sloppy work another time.

Catching the Unusual Defect

He is faced, too, with the occasional, the unusual and intermittent digression from a product standard of appearance or workmanship. Some undesirable deviations may not appear oftener than twice a year and then only on a few units of the product, but the inspector must be alert. Painters were spraying the ceiling and walls of a factory passageway. A trucker passed through on his way to the assembly department with several skids of newly enameled black frames. At the end of the assembly line, a little later, an inspector caught six of the household gadgets, dispersed among a day's output of several hundred, dotted with tiny blobs and spatters of white paint.

A plastics manufacturer suffered a rash of warped covers which was traced to a single hour's moulding, a trouble that had never occurred before and that never appeared again. Aeroplane manufacturers have adopted the term "gremlins" for inexplicable, erratic troubles. When the heat is turned off in the spring and summer's humidity appears, rust will suddenly show up, seemingly in less than an hour's time, on all iron and steel parts unless they are constantly treated for rust prevention — a seasonal difficulty. The list of "sabotaging" gremlins is legion: blisters, flaking, ripples, blowholes, soft spots, broken braid, corrosion, smudge marks, tiny cracks, foreign substances, grit — things that occur only once or so seldom that the causes of them cannot be readily traced or in any manner assigned to the regular process. Discovering the unusual and abnormal is part of the inspector's job.

The Inspector Should Not Establish His Own Standards

In discussing tolerances, in an earlier chapter, the implication was that tolerances are established by design, engineering or similar groups in a plant. In other words, an inspector would not be expected to say what the tolerances should be for a certain type or piece of work. Exactly the same practice should be followed in regard to general standards, although unfortunately such is not usually the case. No inspector should write or establish specifications, tolerances or standards, on the theory that a man cannot fairly judge his own legislation. We all have read of the situation in some villages where one man, as first, selectman, voted a speeding ordinance and then as constable arrested a speeder and finally, assuming his role of local magistrate, decided on the guilt of the hapless tourist.

From a practical viewpoint, the inspector who sets tolerances and standards will almost inevitably either judge work too severely or too readily hedge from a previous decision. It is easier to stop smoking when the doctor orders it than it is to live up to your own New Year's resolution. The inspector's observation of work and his judgment, even in borderline situations, is much more objective, dispassionate and fair if standards have been established by someone else. In common industrial practice he is not often required to establish tolerances or similar definite specifications, but more times than not he is looked to for setting and demonstrating standards. Therefore he should, as far as possible, arrange for having

each and every standard he needs to use established either by a supervisor, by some sort of committee action or by the equivalent engineering action. Even though the inspector should be in good position to recommend a standard, the opinion of someone separate from routine inspection or production should also be obtained as to its practicability and value.

When the Inspector is Over-ruled

Inspectors, even the best of them, are subject to being overruled. At any time one of his decisions may be reversed by someone of greater authority. The fact that the work is okayed after an inspector has rejected it may not stem from any lack of skill or judgment on his part. He may be overruled because of conditions beyond his control — the fact, for instance, that sheer production requirements or economics demand the acceptance of definitely below standard work for a temporary period. Or the work may be borderline, anyway, and one man's opinion is thought to be about as good as another's. Changes in tolerances, specifications and standards may have been authorized without the inspector knowing it. Human inconsistency, whimsy, snap decisions or some form of what might be called local politics too often play parts in the overriding of inspectors' decisions. Again, the decision may be to try to salvage the rejected work.

The reason, however, this discussion is brought up here is to make two suggestions to an inspector. One is that where the reversals are occurring too frequently and too consistently on any particular item, the inspector should make every effort to get the standards officially changed — usually broadened — to accommodate the line of thinking in vogue. The other recommendation is that the inspector must make clear-cut decisions. If he frets over potential reversals of his own findings, he soon reaches a state of mind where he is utterly unable to make close decisions. The act of judging conformance should be fenced off from the function of disposing of the goods afterward.

In judging conformance the successful inspector attempts first to secure the facts. Secondly, he tries to be consistent. What was rejectable yesterday is rejectable today. Finally, he makes decisions based on the situation at hand as independently as possible of contingent or extraneous conditions.

CHAPTER 5

Basic Principles and Techniques of Measurement

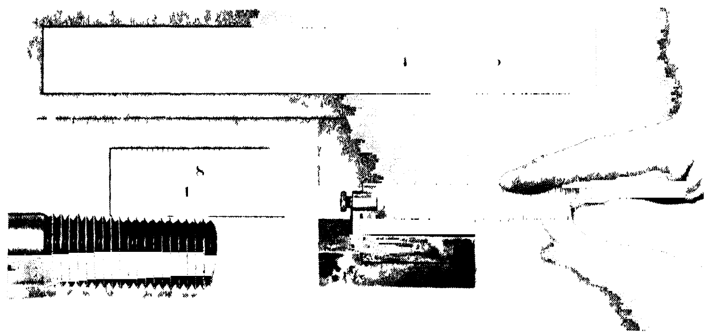
Measurement is the most important function of industrial inspection. The word inspection generally brings to mind precision measurement. While linear measurement is usually thought of, an inspection may mean reading watts, amperes, oscillations or other electrical units. Products may have to be weighed in pounds, ounces or grams; a process may be timed with a stop watch. Hardness, elasticity, viscosity, torsion, temperature, are common inspection terms. Counting what can be seen in the field of a microscope is a form of measurement. In many plants the inspector delves in the fields of physics, chemistry and metallurgy and measures density, humidity, alkalinity or grain size. The whir of ball bearings is registered on an audiometer.

Perhaps the first conception of linear measurement came from watching grandmother use her tape measure or yardstick. Later there was a ruler in a school box. Linear measurement became of more exacting importance to the boy when he first sawed boards for a hut or watched the referee pace off a penalty on the football field. We learned back there that the eye and the sense of touch must be aided by some sort of measuring method, even if it were only two knots in a length of string, in order to make things the way we wanted them to look.

How to Use The Steel Rule Correctly

The primary factory measuring tool or aid in the inspection of machined products is ordinarily the steel rule. A picture of a standard 6-inch machinists' steel rule (sometimes erroneously called a scale) is shown in Fig. 1, along with two illustrations of common uses.

The steel rule as a commercial instrument is being, itself, more or less deliberately glossed over right here because the reader is presumed to have had some shop experience with it and because more particular attention needs to be paid to some of the basic theories of measurement. The steel rule forms a



Courtesy of Brown & Sharpe Mfg Co

Fig. 1. Typical uses for a standard machinists' rule

simple example around which to describe many of the principles of measurement which even experienced mechanics have never correctly learned or else neglected. Also it may be helpful in the same discussion to point out a few of the common errors into which not only the beginner but many of the more experienced fall in using the steel rule itself.

Fig. 2. (Left) Incorrect method of using a steel rule. (Right) Correct method.

If you want accuracy, the steel rule should never be used in the manner shown at the left in Fig. 2. It is much better to butt the piece against a knee, or some similar flat surface, and measure as shown at the right in Fig. 2. The point is that

the end of the steel rule is liable to be worn, rounded, or its corners may be crushed in. The condition may not be apparent to the casual glance but it can exist in sufficient degree to produce errors in reading measurements. (Magnify the zero or working end of a steel rule in an optical comparator. The warning above may then seem worth heeding.) Another good reason for measuring in the fashion just described is the fact that the edge or corner of the workpiece being measured may not be sharp and square. And still more to the point — it is harder to bring the end or corner of the rule coincident to the edge of the workpiece accurately than it is to coincide one of the graduation lines in the manner of measuring about to be described.

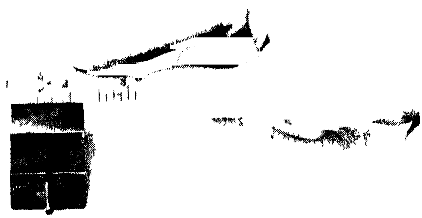


Fig. 3. Best method for obtaining accurate measurements with a steel rule.

Probably the best way to use the steel rule is pictured in Fig. 3. It is better to use the 1-inch mark on the rule for reference rather than the 0-inch end (not forgetting of course to subtract 1 inch from the reading actually taken). The rule should be stood up on the work more or less perpendicularly, rather than laid flat, as in the left view of Fig. 2.

Steel rules called hook rules can be purchased, the little bars or hooks on the end of which serve in the place of butt plates (as shown in Fig. 4). Where, however, the hook rule is to be relied on for fairly precise measurements, the "hook" must be checked regularly to be sure it has not loosened, that it is still square with the length of the rule, and that it has not worn back nor rounded off. A general difficulty in connection with various helpful attachments offered with measuring in-

struments to make their use easier or quicker, is the fact that the accuracy of the attachment itself is too seldom questioned. The attachment, like a hook or a caliper jaw on a steel rule, becomes relied on and yet by its very nature. design, and use proves to be the item that becomes bent, worn or loose and makes the use of the rule inaccurate.

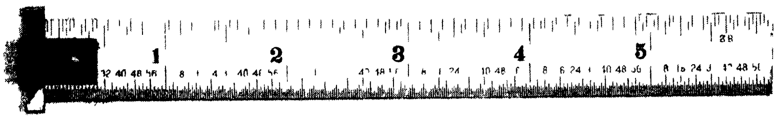


Fig. 4. Steel rule equipped with hook for accurate referencing.

From Reference Point to Measured Point

Right here, while the practice of measurement with the steel rule is being discussed, might be a good place to describe one or two elementary and basic principles of measurement.

Any linear measurement can be broken down into two "points": the reference point and the measured point. Actually the "points" may be true points, in the geometric sense, or they may be a pair of lines or edges, two planes or sides, or two circles. But though we measure between two walls or two edges, if the point to point conception of measuring is kept in mind, the results will be more accurate.

We measure *from* the reference point *to* the measured point. In using any measuring instrument we set the instrument first on the reference point and move the instrument — or read along it — until we find the measured point. (In the case of large, heavy gages and measuring instruments, where the work is brought to the instrument rather than the instrument to the work, the same principle is followed. The work is "referenced" first on the gage's reference surface.)

Where, in the right view of Fig. 2, we butt the steel rule against a knee or parallel we are establishing a firm reference point. If instead of using a butt plate, we index the rule on the edge of the work at its 1-inch mark, as in Fig. 5, the 1-inch mark becomes the reference point. Setting the steel rule on a

reference point and holding it firmly there is just as essential for accuracy of measurement as reading correctly at the measured point, if not more so.

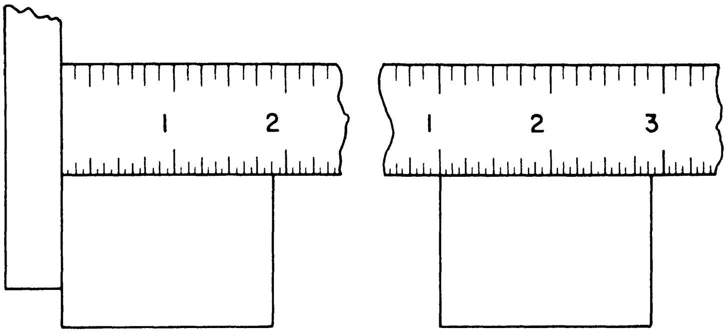


Fig. 5. (Left) Use of butt plate as a reference point. (Right) Use of 1-inch mark as a reference point.

The purpose of the hook rule or a caliper jaw or most any similar accessory is to help establish, conveniently, a firm reference point.

Measuring the diameter of a hole with a steel rule, as illustrated in Fig. 6, forms an excellent exercise for establishing the principle of the reference point and the measured point

Fig. 6. Method used to measure diameter of a hole with steel rule.

in your mind. Here, the 1-inch mark is the reference point. The rule is carefully set on one point of the circumference of the hole so that it can be pivoted about the 1-inch mark. To

get the measurement or the measured point, the rule is swung back and forth slightly along the arc of the hole opposite the stationary 1-inch mark — the 1-inch mark acting as the pivot or hinge — until the opposite point, on the longest chord which is the diameter, is located and this diameter is correctly measured and read.

When a succession of similar pieces is to be measured, the accuracy of measurement and the comparison of the dimensions of the piece are facilitated when the reference point for each piece is approximately in the same location and the measurements are all taken in the same direction. This idea is illustrated in Fig. 7 where, because a counterbored tapped hole marks a direction on a shaft, the diameter measurement is perhaps more consistently taken in the *a* direction rather than haphazardly.

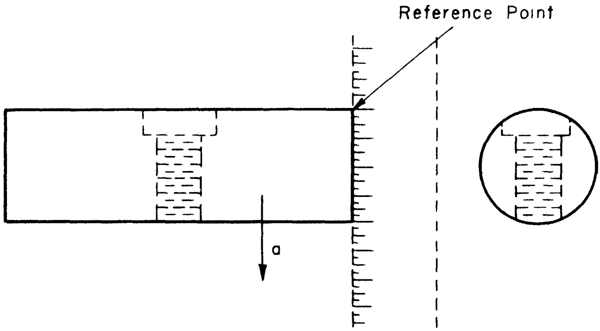


Fig. 7. Use of a similarly located reference point when succession of similar pieces is to be measured.

Repetition is the Test of an Accurate Measurement

The test of a measurement is *repetition,* that is, repeated readings that are the same. If you measure the diameter of a shaft or the width of a bar several times in the same location and get different readings, you are probably not taking the measurement accurately. Thus, improperly using the worn end of a steel rule as a reference point, as in Fig. 2 (left), will probably fail to give repeat readings. The lack of repetition can also indicate that something is wrong with the measuring instrument itself. While such a condition would not ordinarily show up with the proper use of the standard steel rule, lack of repetition will show up loose and worn hooks or caliper

jaws. Where the inspection of a piece is at all fussy it is well to repeat each measurement as a check on your accuracy and your ability to measure.

The graduations or marks on a steel rule have intrinsic width, especially under a glass, no matter how carefully they have been etched or engraved on the rule. Manufacturers of this type of equipment attempt to keep the width of the lines as near .003 inch as possible. Since the steel rule is not supposed to read closer than 1/64 inch (.015 inch), any error produced by the width of the graduations would not exceed one-fifth the natural ability for reading the finest division on the rule. Even so, especially when a magnifying glass is used, the width of the graduation mark might cause an error in a reading, or seem to. Where the lines on a steel rule are engine engraved, the graduations are really sharp V's, the apparent width of the marks being the open or upper ends of the V's. Hence, in using a rule on very fine work, measure from the center of one graduation — the reference point — to the center of the graduation marking the measured point.

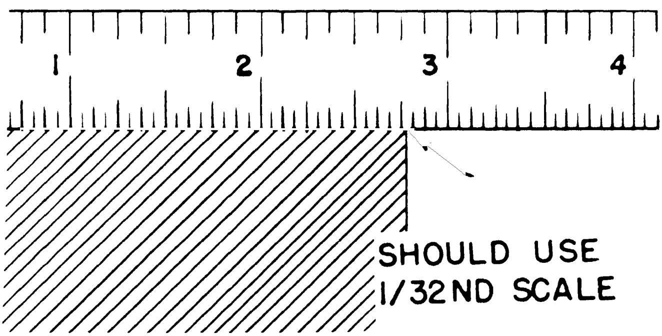


Fig. 8. When a reading falls between graduations a scale with finer divisions should be used.

Discrimination Means Size of Scale Unit

Steel rules ordinarily have four scales — 1/8-inch, 1/16-inch, 1/32-inch, and 1/64-inch. If a certain scale has been chosen and if the reading falls between graduations, then measure with the next finer scale. Fig. 8 portrays what is meant. The number of graduations on an instrument or the degree to which it subdivides an inch, for instance, is known as its *discrimination*. Except where it is absolutely necessary because

of lack of equipment, an estimate of the reading between graduations should never be made. In the first place it is a lazy habit; better look around for apparatus with finer discrimination. In the second place none of us are as expert as we think we are at estimating. When the actual reading falls between graduations, make up your mind whether you are going to choose the lower or higher graduation value for your reading, if a finer scale is not available.

The inch on the finest scale on most steel rules is divided into sixty-fourths. It has been found through the years that few humans can determine measurements accurately closer than 1/64th of an inch, at least without the aid of a magnifying glass. Then too, without mechanical aids such as clamping and fine adjustment devices, few of us can hold a steel rule steady enough to get an accurate reading below a 64th. Some mechanics claim an ability to read and measure down to .005 inch but they have difficulty proving consistent hour-in and hour-out accuracy.

Parallax Introduces Error in Scale Reading

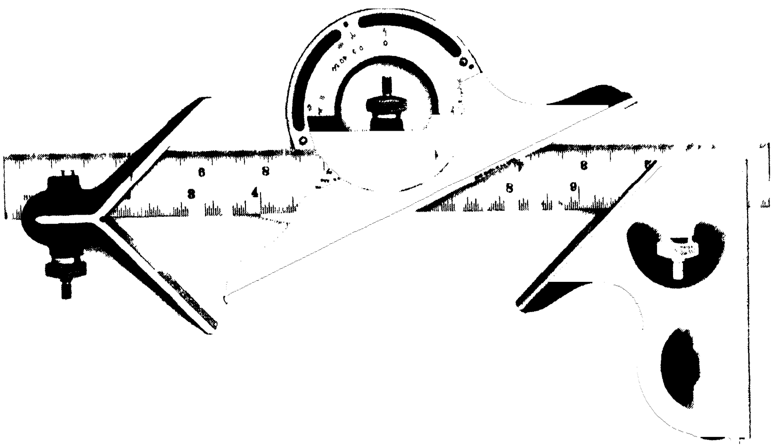
In boasting of their ability to detect a difference in measurement of .005 inch or .010 inch (1/64 inch is .0156 inch) they forget the error of parallax even though they may be able to hold a steel rule steady enough. Parallax is the apparent displacement or shifting of an object caused by the change in position of the observer. Look squarely at the face of a clock and read the time. Then walk several feet to one side and honestly read the time there as you actually see it obliquely across the hand. The clock will read several minutes slower or faster, depending on which angle you view it from. All of us have unwittingly made this error.

If your nose and eyes are squarely over the reference reading on a steel rule, you will make somewhat of an error if you simply turn your eyes and try to read a graduation several inches obliquely along the rule. Parallax will result in an error of several thousandths of an inch if you are trying to estimate some measurement finer than 1/64 inch. Even though you move your head, nose and eyes over the several inches from the reference point to the measured point, you may find your hand, holding the rule, has unconsciously traveled with the body motion and moved the rule across the work a few thousandths of an inch, thus making an error in the measurement.

Look Out for Manual Errors

With whatever instrument you measure, be it a steel rule or a supersensitive gage, let the instrument do the work. Don't cramp its style. Relax, loosen your grip. The hand trembles more readily when you grip a steel rule as if it were a crowbar. The most you want to do in measuring is to set the reference point in position and read the measured point. Hold the rule lightly, but firmly.

Then, there is another common manual error made in measuring, an unconscious one. Suppose it is difficult to decide whether or not the width of a slot is 15/64 inch or 16/64 inch (1/4 inch), and suppose the specifications call for 1/4 inch or 16/64 inch. And more particularly, suppose you really want the slot to measure 16/64 inch. Unless you realize the possibility, unless you make some degree of effort of will, your hand will unconsciously move the rule a trifle in the favored direction.



Courtesy of Brown & Sharpe Mfg Co

Fig. 9. Typical combination set.

Use of the Combination Square

A common commercial variation of the steel rule with attachments is the combination square, Fig. 9. It consists of the steel

rule, the center head, the sliding head or beam, the protractor head, and a scriber.

It is possible to use the steel rule and the sliding head to square a piece with a surface and at the same time determine whether one or the other is plumb. Also, by using the miter, it is possible to lay out 45-degree angles as well as 90-degree angles with the head. Inserted conveniently in the head is a scriber for this purpose. By setting the steel rule flush with the sliding head, it may be used as a height gage directly.

Also, by loosening the rule it is possible to use the combination as a depth gage where micrometer accuracy is not necessary.

The steel rule can be removed from the head, permitting the use of the rule and the sliding head separately. The head can be used as an ordinary level.

By substituting the center head for the sliding head, a center square is obtained for finding the center line of cylindrical objects. This center head is slotted in the center so that the rule, when inserted, bisects the 90-degree angle. In this way, the measuring surfaces become tangent to the circumference of cylindrical work. It is possible to locate the center of a bar.

Fig. 10. (Left) Caliper being used to obtain an outside diameter measurement. (Right) Measuring a caliper setting with steel rule.

The protractor can be inserted on the steel rule in the same manner as the sliding head and center head. The revolving turret can be graduated in degrees from 0 to 180 or to 90 in

either direction. Also the head contains a spirit level to facilitate the measuring of angles in relation to the horizontal or vertical plane.

While it is not a precision instrument, it controls the accuracy of measuring and laying out angles within one degree.

The Calipers — Accessory to the Steel Rule

To an inspector, a pair of calipers is an accessory to the steel rule. A diameter may be measured with the steel rule as indicated in Fig. 6 but a more accurate diameter measurement will likely be gained by calipering and transferring the measurement to a steel rule as shown in Fig. 10.

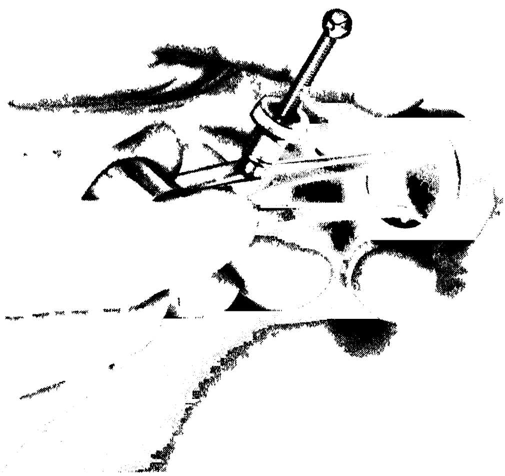


Fig. 11. Measuring an inside diameter with calipers.

Likewise an inside diameter is measured after the manner shown in Fig. 11 and the reading transferred to the rule by holding the rule vertically on a flat surface with the caliper ends against the rule, one caliper end resting on the flat surface.

Measure the True Diameter

Especially in taking an inside diameter (though for that matter an outside diameter, too, or any similar measurement) care must be used to measure the true diameter. Sketches A and B in Fig. 12 show incorrect measurements of an inside diameter. In each case a measurement greater than the true diameter would be obtained. One leg and point of the caliper should be set as the reference point — see sketch A in Fig. 12 — and the caliper should be rocked and adjusted until by "feel" the true diameter, the correct measurement, is secured as at C in Fig. 12.

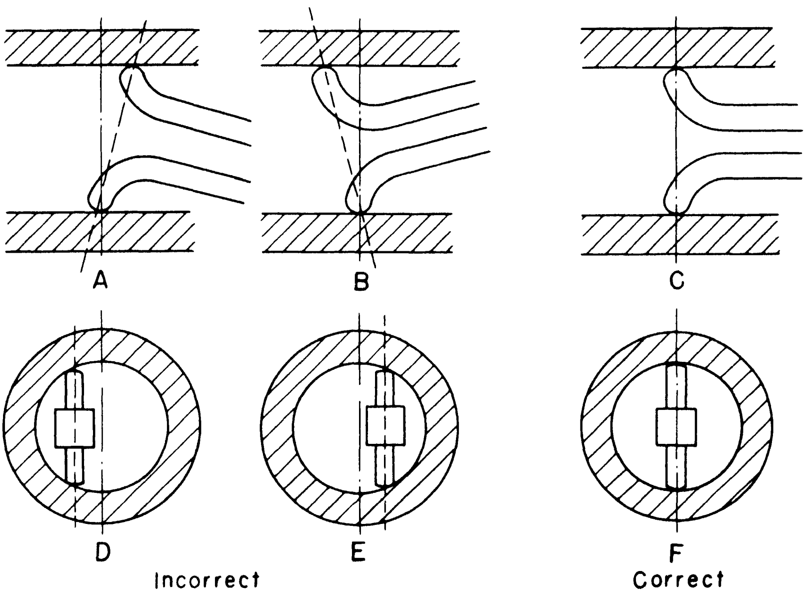
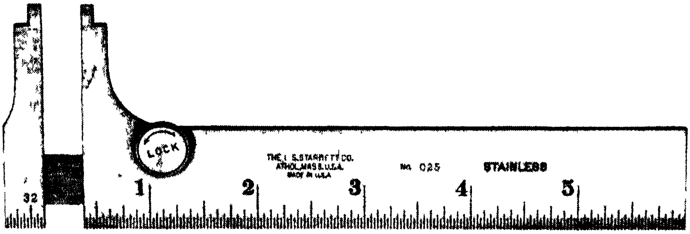


Fig. 12. (A), (B) Incorrect inside measurements are caused by tilting of calipers. (C) Correct method of measurement. (D), (E) Incorrect inside diameter measurements caused by excess calipering pressure which squeezes caliper legs together. (F) Correct method.

At the same time, avoid letting the caliper legs become squeezed together slightly, thus allowing the shorter chord of the diameter circle as at D and E in Fig. 12 to be measured rather than the true, full diameter as at F in Fig. 12.

While calipers are ordinarily used to get diameter measurements, they can also be used to "explore" flat pieces to detect thickness, width, depth, taper or parallelism.

In Fig. 13 is shown a type of caliper which is actually a sliding steel rule that permits a direct reading of the measurement being taken.



Courtesy of The L S Starrett Co

Fig. 13. Direct reading type of inside and outside caliper.

Gaging Pressure Should be Light

Measuring exercises with calipers furnish an excellent setting for discussing gaging pressure. Wherever gages of almost any sort are used, the pressure exerted either by the inspector's hand on the gage or by the mechanism of the gage itself will have a marked effect on the accuracy, uniformity or the repetition in measurements secured. Warnings concerning gaging pressure will be given in connection with measuring instruments mentioned hereafter.

As a general average, recognized gaging pressures vary between half a pound and two pounds. Some precision instruments are deliberately designed to exert measuring pressure of only a few grams. Occasionally circumstances require a gaging or clamping pressure greater than two pounds.

An inspector using a variety of gages and measuring tools, such as calipers, micrometers, snap and plug gages, should certainly practice and practice, like a dentist or surgeon, to develop a light, firm, consistent touch.

A good system to follow is to consider "pencil" pressure — the pressure you exert pressing the point of a pencil against a piece of paper as you write. Put a piece of paper on the platform of a postal scale, for instance. Then, resting the weight of the hand on some surface (like a book) that is about level with the postal scale platform, write with a pencil in

normal fashion on the paper on the postal scale platform and read what the scale dial tells you in ounces or pounds.

From such an exercise try to establish between 12 and 18 ounces finger and hand pressure. Then, mentally, transfer the "feel," this sense of pressure, the firmness with which you grip a pencil, to your use of calipers, to your fingers turning a micrometer screw on to a piece of work or to the insertion of a plug gage in a hole.

A gage, or any hand measuring instrument, need not be lifted and moved the way a dowager raises her teacup from its saucer, her little finger daintily curled, but neither should it be applied like a snagging rasp.

Indicating gages and similar measuring mechanisms, as will be seen, have spring controlled jaws and anvils, thus automatically establishing practically uniform gaging pressure independent of the inspector's actions.

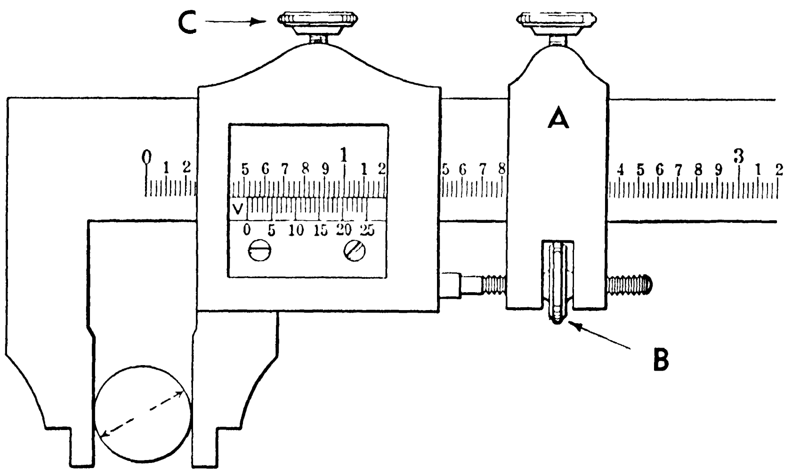


Fig. 14. Typical vernier caliper showing vernier scale V and fine adjustment nut B.

Use of the Vernier Calipers

Studying common and conventional inspection tools from the viewpoint of discrimination, we come next to equipment having a vernier scale. The ordinary classes of this sort of apparatus are the vernier caliper, the vernier height gage and the vernier depth gage. Where the steel rule has a discrimina-

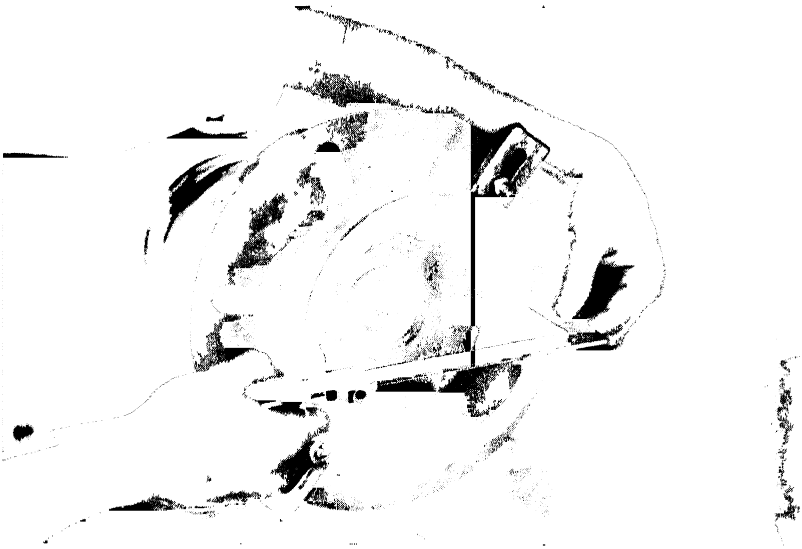


Fig. 15. (Upper) Vernier caliper being used to measure an inside diameter. (Lower) Making an outside measurement.

tion of 1/64 inch or .0156 inch, standard vernier equipment can be used to measure to one-thousandth of an inch (.001 inch).

A typical vernier caliper is illustrated in Fig. 14. A couple of vernier calipers in action are shown in Fig. 15.

Vernier calipers, height gages or depth gages are essentially steel rules. But the rule length, from 6 inches to 48 inches — depending on the size and model of instrument, has been not only accurately divided off or graduated, but a sliding jaw with a so-called vernier scale attachment has been added (see Fig. 14) as a visual aid, in subdividing the smallest graduation on the rule. Each inch of the main scale is subdivided into ten parts and each of these tenths of an inch again subdivided into quarters. (Study Fig. 16 carefully.) Hence, each *indi-*

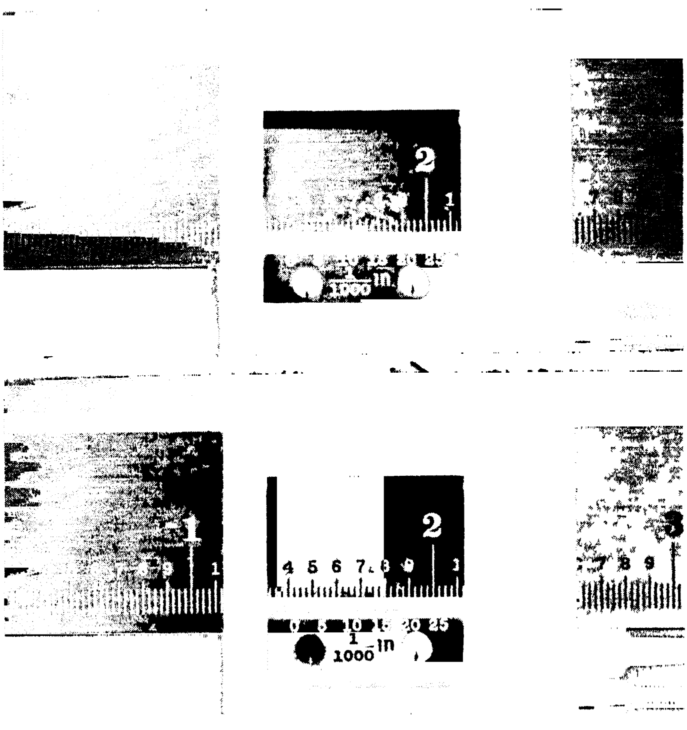


Fig. 16. Vernier caliper set to two different dimensions· (Upper) Set to 1.436 inches. (Lower) Set to 1.425 inches.

vidual graduation on the standard, commercial vernier caliper main scale represents 1/40th of an inch.

The "vernier scale," which slides along the main scale, see Fig. 16, contains 25 subdivisions in the same total length or span embraced by 24 subdivisions on the main scale. The difference, then, between a main scale subdivision and a vernier scale subdivision is 1/25th of a main scale subdivision.

A main scale subdivision is 1/40th of an inch. 1/25th *of* 1/40th is 1/1000 or .001 inch.

Looking at the top illustration in Fig. 16, you can read by eye the 1 inch, the 4/10ths of an inch (equalling 1.4 inch up to this point), and the 1/40-inch subdivision immediately to the left of the vernier scale zero division. In other words, you can read by eye: 1 inch plus .4 inch plus 1/40 inch or .025 inch, which totals 1.425 inches.

This is not the accurate reading, however, since the 0 index on the *vernier scale* shows it to be greater than 1.425 inches.

The additional, exact thousandths of an inch are secured by reading the "coincidence" of a line on the *vernier scale* with *any* line on the main scale. Read only the *vernier scale* coincident line. In the top view of Fig. 16 that *vernier scale* line is number 11, which is the only one that exactly coincides with a line on the main scale. Add .011 inch to 1.425 inches and get the correct instrument reading of 1.436 inches.

Had the vernier scale index of 0 and the vernier scale number 25 *both* been coincident with main scale subdivisions, then the true instrument reading would have been the *main scale* graduation marked by the vernier scale 0, or 1.425 inches, as illustrated in the bottom illustration of Fig. 16.

In routine shop inspection practice, it is best to find the coincidence of a specific vernier scale line to any main scale graduation with a glass in order to overcome any possible error of .001 inch, or so, by not determining the exact coincidence line on the vernier scale.

Proper Manipulation Avoids Errors

Experience with vernier calipers will show quickly that errors in measurement are not usually made by misreading the vernier scale or by incorrectly adding the vernier scale coincident reading to the relevant main scale reading but rather from manipulation of the vernier caliper and its jaws on the workpiece.

In measuring an outside diameter, be sure the caliper bar and the plane of the caliper jaws are truly perpendicular to the workpiece's longitudinal center line. In other words, be sure the caliper is not canted, tilted or twisted. The warning needs to be reemphasized because the relatively long, extending main bar of the average vernier calipers so readily tips in one direction or the other.

Always, with vernier calipers, use the stationary caliper jaw on the reference point and obtain the measured point by advancing or withdrawing the sliding jaw. For this purpose, most all vernier calipers are equipped with a fine adjustment attachment as a part of the sliding jaw.

In general, grip the vernier calipers near or opposite the jaws; one hand for the stationary jaw and the other hand generally supporting the sliding jaw. Don't, in other words, hold the instrument by the more or less overhanging "tail" formed by the projecting main bar of the calipers.

Referencing the solid jaw on the work, move the sliding jaw solidly into position against the workpiece. Then back the sliding jaw off slightly and tighten the clamp *A*, Fig. 14, holding the fine adjustment nut *B*. Move the main sliding jaw forward or back, as required, by turning the fine adjustment nut, moving the caliper jaws on the work with the light touch of the pickpocket, until you believe the calipers are in proper position and that you have the correct "feel" or gaging pressure equivalent of around sixteen ounces. Tighten the sliding jaw clamping nut *C*.

Before you read the vernier, try the calipers again for feel and location. Very likely, clamping the sliding jaw has thrown off the precise homing of the jaws and you will have to compensate for the error by once more loosening the sliding jaw section and taking part of a turn with the fine adjustment screw.

Where you use vernier calipers for inside diameter measurements, even more than usual precautions will have to be taken to rock the instrument a little on the reference point to be sure the measured point falls on the true diameter you are after. This action or technique is known in gaging parlance as *centralizing*.

Most shop disputes between machine operators and inspectors over close measurements arise from handling the instrument improperly. The vernier caliper is one type of gaging apparatus which requires skilful manipulation.

Testing the Accuracy of Vernier Calipers

Test the accuracy and natural wear and warping of vernier caliper jaws frequently by closing them together tightly or setting them to the 0-0 point of the main and vernier scales. With jaws in closed position, hold the calipers up to the light.

If there is wear, spring or warp, you are most likely to see a knock-kneed condition like that illustrated in sketch A of Fig. 17. If in your opinion the condition would produce measurement errors greater than .0002 inch, the instrument should be sent back to the manufacturer for repair. (Remember, in sighting caliper jaws against a light, the smallest gap you can probably discern is half a ten-thousandth — .00005 inch.)

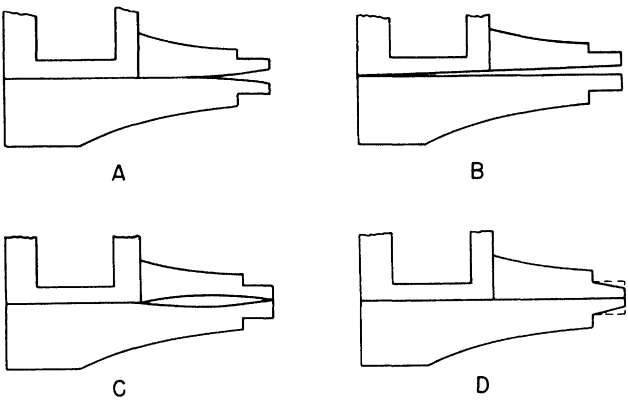


Fig. 17. Various jaw conditions which result in inaccurate caliper measurements.

If the vernier scale is set at 0-0 and a strip of light appears between the ostensibly closed jaws, though no appreciable wear itself — or warp — shows, the jaws can then be closed tight and the vernier scale readjusted to a new 0-0 by means of the two adjusting screws provided on the vernier scale (see Fig. 16). Also set the caliper jaws on a 1-inch gage block or suitable 1-inch master and in like manner check and reset, if necessary, the vernier scale 0 at the main scale 1-inch graduation. Or if the calipers are used mostly within a range of dimensions, close to, say, 3 inches, or 9 inches, or 18 inches, the vernier scale setting test should be made on master cylinders or blocks* of corresponding size.

Returning to Fig. 17, a condition like that shown in sketch B is sometimes seen. This probably means that the sliding jaw frame has become worn or warped so that it does not slide squarely and snugly on the main caliper beam. The reconditioning job probably can be better executed by the gage manu-

* See Chapter 7 for a description of these.

facturer, if a simple adjustment of the gib and spring in the sliding member does not correct the trouble.

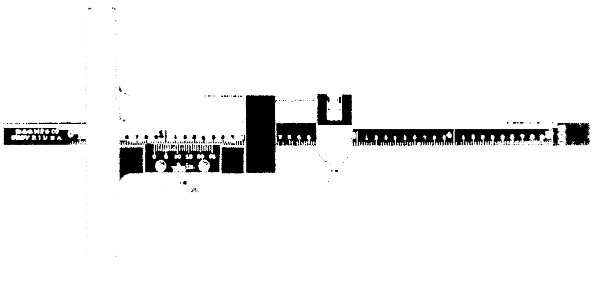
Where vernier calipers are used mostly for measuring inside diameters, the jaws may become bowlegged as in sketch C of Fig. 17, or their outside edges worn down as in sketch D.

Most vernier calipers are provided with two vernier scales and two main beam scales. One is marked for outside dimensions, the other for inside dimensions. The more skilled mechanics seldom use the "inside" scales. With caliper jaws in proper repair and closed tightly, measure across them with a micrometer as shown in Fig. 18, recording the dimension.

Fig. 18. Measuring the jaws of a vernier caliper to determine the amount to add to the "outside" scale reading when making inside diameter measurements.

Then, when measuring an I.D., read the "outside" scale of the instrument and add the known micrometer reading, just mentioned, to the outside scale reading to get an I.D. measurement which is usually more accurate than taking a reading directly on the instrument's inside scale. The above technique also obviates errors due to the wearing down of the outside surfaces of the caliper jaws.

Vernier calipers should not be treated or used as a wrench or hammer. This is not to imply that a good mechanic or inspector would be so grossly careless, but to emphasize that vernier calipers are not rugged instruments. They should be set down gently — preferably in the box they came in — and



Courtesy of Brown & Sharpe Mfg. Co.

Fig. 19. Vernier depth gage.

not dropped or tossed aside. They must be kept wiped free from grit, chips and oil. Bring vernier calipers to the workpiece; don't clamp the workpiece in the caliper jaws and wave them around in the air.

Vernier Depth Gages

A vernier depth gage is illustrated in Fig. 19. As an instrument, it is essentially a depth rule with vernier attachment and markings, and a base or anvil. In general, the base or

Fig. 20. Vernier depth gage being used to measure a depth on a block.

anvil is rested on or against a reference surface and the scaled beam or tongue is pushed beyond the base to contact with the measured point as shown in Fig. 20. Readings taken at the

vernier attachment show directly the length of beam or tongue protruding beyond the base.

The depth gage is carefully made so that the rule or beam is perpendicular to the base in both directions. The end of the beam is square, and flat, like the end of a steel rule, and the base is flat and true, free from curves or waviness.

A depth gage itself then, because of its own careful construction, will give a true measurement when used properly, but it is easier to make errors with it, due to manipulation, than with almost any other form of measuring apparatus.

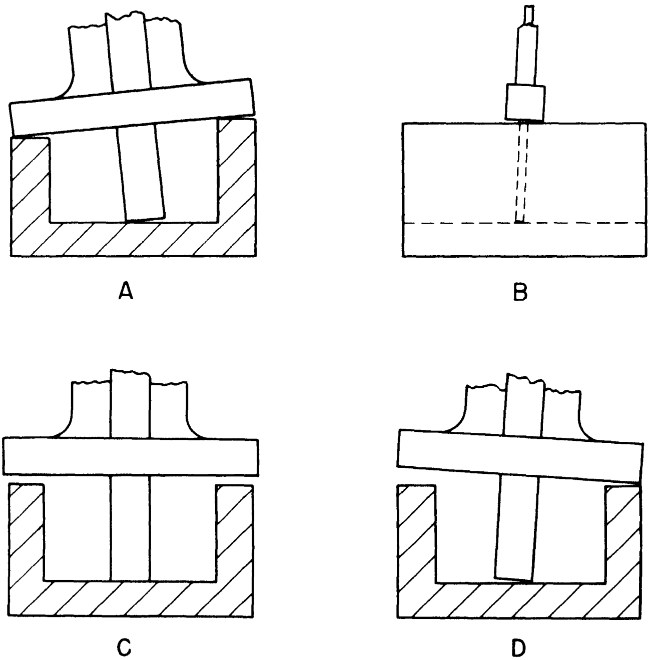


Fig. 21. Several depth measuring methods which produce erroneous measurements.

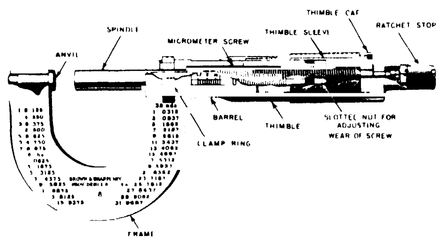
First of all, make sure the reference surface, on which the depth gage base is rested, is satisfactorily true, flat and square. Measuring depth is a little like measuring an inside diameter. The gage itself is true and square but it can be imperceptibly tipped or canted, because of the reference surface perhaps, and offer an erroneous reading as shown diagrammatically in exaggerated fashion in Fig. 21. Another type of error

appears in sketch B of Fig. 21, illustrating how the gage may be unconsciously tipped forward or backward.

The most common error, however, is diagrammed at C in Fig. 21. In using the depth gage, the base or anvil may be at first firmly rested on the reference surface. The tendency then is to slide the beam or tongue against the measured point with so much pressure that the base is lifted as shown at C — perhaps only an imperceptible thousandth or so — or the point pressure cants the base a trifle as at D. In using a depth gage, press the anvil firmly on the reference surface and keep several pounds hand pressure on it. Then, in manipulating the gage beam to measure depth, be sure to apply only standard, light, measuring pressure — 8 to 16 ounces — like making a light dot on paper with a pencil.

Other Types of Vernier Equipment

Other typical pieces of vernier equipment are the vernier height gage and the vernier protractor. Since the height gage is so commonly allied with surface-plate practice, a discussion of its use is omitted here, to be included later, where its use in connection with surface plate measurement practice is described. In a similar vein, a discussion of the vernier protractor is included in the description of tools and methods of angular measurement.



Courtesy of Brown & Sharpe Mfg. Co.

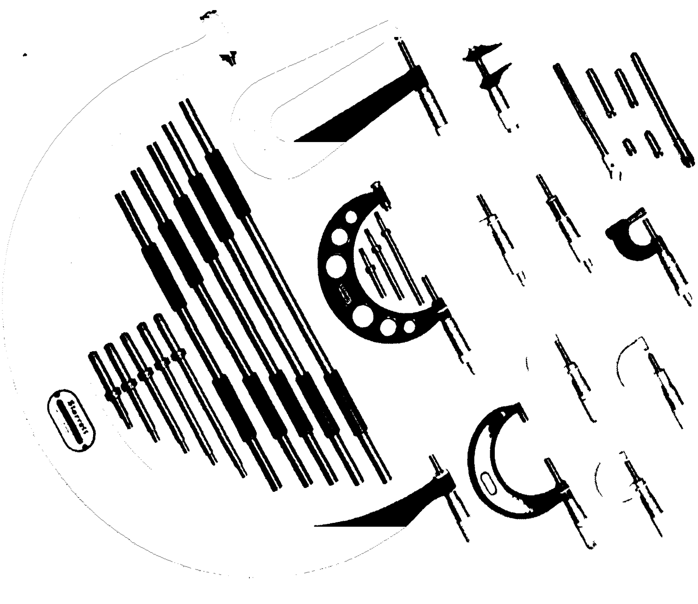
Fig. 22. Section through a micrometer showing principal parts.

Understanding the Micrometer

The principle of the micrometer, which is actually a special form of caliper, is purely that of a screw turning in a nut and of the point or end of the screw advancing toward or receding from the opposite anvil of a C frame. The common commercial names for the various parts of a micrometer are given in the sectional view of Fig. 22. The reader should

study Fig. 22 to familiarize himself with the following parts which will be frequently referred to in the subsequent discussion: *frame, anvil, spindle, barrel, thimble, screw, ratchet or stop, and clamp ring or locking screw.*

Technically the "anvil" is the fixed measuring surface clamped in the frame. In our terminology it is the instrument's reference surface. Sometimes, however, the measuring surface of the spindle — the movable unit — is referred to as an anvil. Both tips are described many times as the micrometer's jaws. In this book, however, the fixed or reference measuring surface will be consistently called the anvil and the movable measuring surface, for securing the measured point, will be called the spindle.



Courtesy of The L. S. Starrett Co.

Fig. 23. Various types and sizes of micrometer calipers commonly used.

The term micrometer, itself, or micrometers, is almost invariably applied to the standard, now conventional, 1-inch micrometer caliper. There are also inside micrometers, thread micrometers and other special models such as are shown in Fig. 23. As can also be seen from this illustration micrometers come also in 2 inches, 3 inches and up to 12 inches in

Fig. 24. Methods of using various types of micrometers.

range or span. So, as a matter of terminology, the plain word micrometers or "mikes" can be assumed in this text to refer to the 1-inch micrometer caliper, and the words 3-inch, or inside, or thread, or some other descriptive term will be used with the word micrometer when an instrument other than the 1-inch micrometer is being referred to. A few different kinds of micrometers are shown in use in Fig. 24.

Reading the Micrometer

The screw of the micrometer is purposely cut 40 threads to the inch so that when it is turned in one revolution, its point has advanced 1/40 inch. The micrometer thimble, an enlarged sleeve or band, surrounding the screw and fastened to it, has twenty-five gradations engraved on its periphery in such a manner that the eye can readily register 1/25 of a turn of the screw. So, if the screw is turned in 1/25 of a full revolution, the point of the screw has advanced 1/1000 inch, because 1/25 of 1/40 is 1/1000.

The 1-inch length of the *barrel* of the micrometer (examine Fig. 22 again) is divided into tenths of an inch — 0.1 inch, 0.2 inch, etc. And each tenth is graduated into four equal divisions of 0.025 inch. In other words — see Fig. 25 — each subdivision in succession, within each tenth division on the barrel, reads respectively 0.025 inch, 0.050 inch, 0.075 inch.

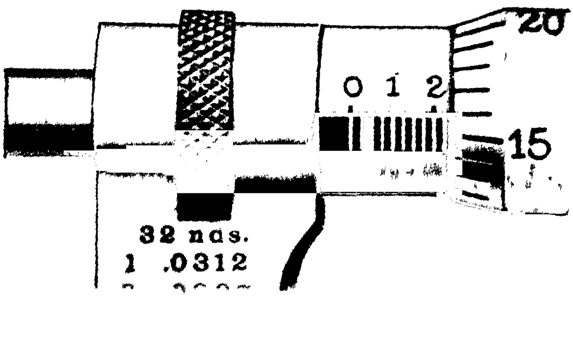


Fig. 25. Micrometer set to measure 0.241 inch.

Hence, to read the micrometer setting in Fig. 25, the edge of the thimble has uncovered first the "2" or 0.2 barrel division. Secondly it has uncovered the 0.025-inch subdivision, making the reading up to this point 0.2 + 0.025 or 0.225. The part of the subdivision left registers on the thimble itself as "16" or 0.016. Adding 0.016 to 0.225 gives 0.241 as the micrometer reading. It means that the gap between the micrometer jaws is 0.241 inch.

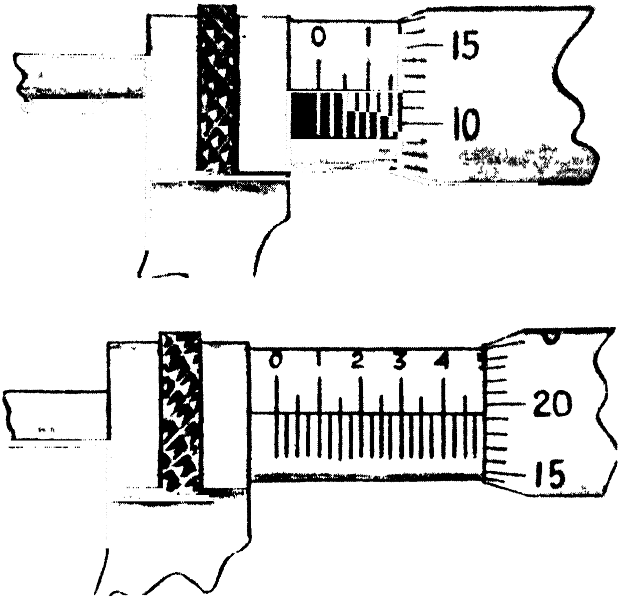


Fig. 26. (Upper) Micrometer set to measure 0.162 inch. (Lower) Micrometer set to measure somewhat more than 0.494 inch.

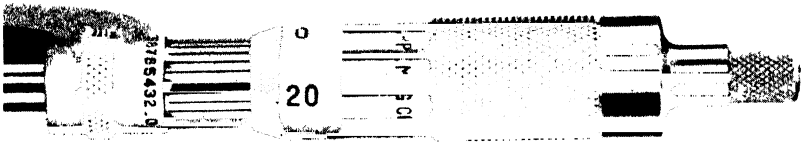


Fig. 27. Vernier giving reading in tenths of thousandths. Reading is .0004 greater than thimble reading (not shown).

Figure 26 shows micrometers reading 0.162 inch and 0.494 inch, respectively. However, the 0.494 reading in Fig. 26 does not fall squarely on a thimble division — the actual reading is 0.494 inch and some ten-thousandths of an inch more. For reading the additional ten-thousandths, the micrometer is equipped with a vernier scale also engraved on the barrel. Note in Fig. 27 that a *thimble* engraving is coincident with the "4" vernier line, which means that 0.0004 inch is to be added to the thimble reading (which is not visible in this illustration).

Perhaps the best order in which to discuss the use of a micrometer for our purpose is to suggest a situation that is not entirely hypothetical in the average factory inspector's routine: that of coming into a shop area to measure certain product dimensions and using perhaps his own micrometer but, equally likely, using micrometers available in the area.

Cleaning the Micrometer

First, naturally, the micrometer should be wiped free from oil, dirt, dust and grit. Nothing probably advertises a good inspector faster than the fact that he instinctively and consistently requires clean intruments. By this habit he inspires confidence on the part of others watching him or dependent on his decisions, and confidence in the measurements he takes.

Many times, when a micrometer feels gummy and dust ridden and the thimble fails to turn freely, inspectors are prone to dunk it bodily in kerosene or some similar solvent. Such practice, however, is not recommended. It is much better to have someone who knows what he is doing take the micrometer apart and thoroughly wash each component free from gum and dirt. Just soaking the assembled micrometer fails to float the dirt away; it may get softened up for a minute or so or transferred to another section of the mike. Besides, the apparent stickiness of the micrometer may not be due at all to grit and gum but to a damaged thread or to a warped and sprung frame or spindle.

Assuming reasonable cleanliness and a free-running instrument up to this point, the next step is to clean the measuring surfaces of the anvil and spindle. Technically, this function should be performed every time the micrometers are used. Screw the spindle lightly but firmly down on to a clean piece of paper held between spindle and anvil as shown in Fig. 28.

Pull the piece of paper out from between the measuring surfaces. Then unscrew the spindle a few turns and blow out any fuzz or particles of paper that may have clung to the sharp edges of anvil and spindle.

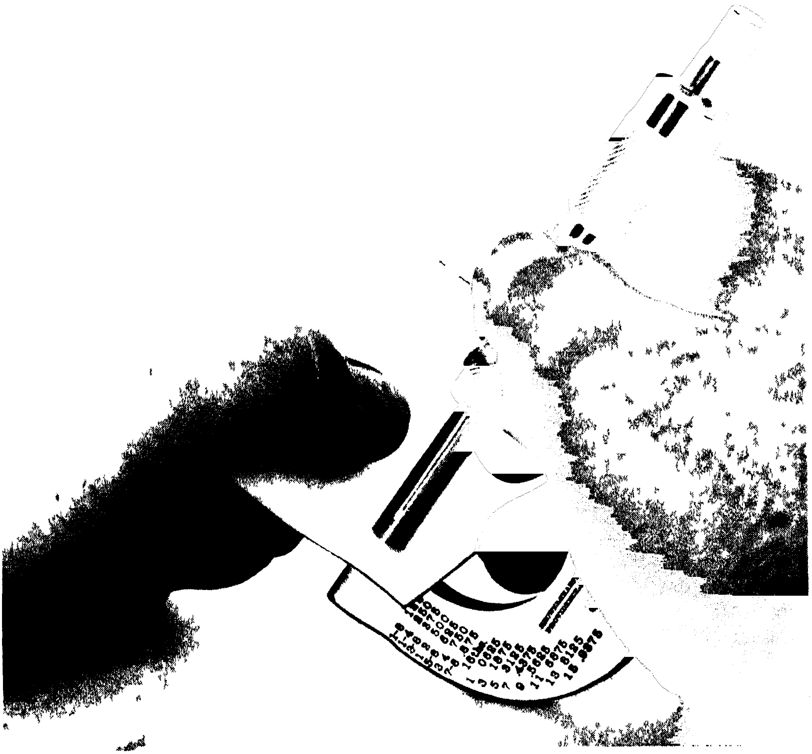


Fig 28 Cleaning the measuring surfaces of a micrometer caliper.

Here is a good place to emphasize a condition that characteristically misguides an inspector into errors of precision measurement. A light film of oil or grease in itself may not disturb the accuracy of the reading, unless precision in something like a millionth of an inch is required, because the oil film is nearly impalpable. But oil is a collector of dust, dirt, grit and particles. The product of human sweat glands is also a ready offender. A firm ridge of dirt several thousandths of an inch in elevation can readily collect — unnoticed — on the anvils of measuring equipment.

Testing for Parallelism and Flatness of Measuring Surfaces

The next test of a micrometer's reliability should be that of parallelism and flatness of the measuring surfaces, checking for conditions similar to those exaggerated in sketches A and B of Fig. 29.

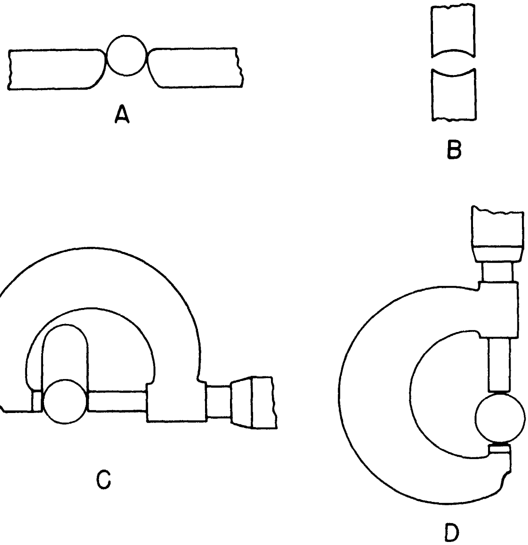


Fig. 29. (A) and (B) Two conditions of micrometer measuring surfaces which result in erroneous measurements. (C) and (D) Testing for conditions shown in (A) and (B), respectively.

For a quick test of parallelism use a pencil size steel rod, preferably with a very smooth ground or lapped surface. The test piece should be three or four inches long. Catch the rod lightly between anvil and spindle near one end of the rod. Tip the micrometer and rod into horizontal position as indicated at C in Fig. 29. If some condition like that shown in sketch A exists, the rod will readily pivot on the high spots and turn or sag down if it is held in the mike as shown at C.

Lack of true flatness (sketch B of Fig. 29) can be checked by "exploring" the measuring surfaces with a precision ball as at D. The ball is moved from location to location around the measuring surfaces. Great care, however, must be used in applying uniform spindle pressure and in taking the reading for each location of the ball to detect minute errors in surface flatness.

The most foolproof test of micrometer measuring surface conditions is with an optical flat, an operation pictured in Fig. 30. This particular type of test and the reading and interpretation of light bands may be better understood after the study of optical inspection equipment in Chapter 11. The optical flat test has the advantage of disclosing readily and accurately all combinations of wear conditions — waviness, hollows, humps and lack of parallelism.

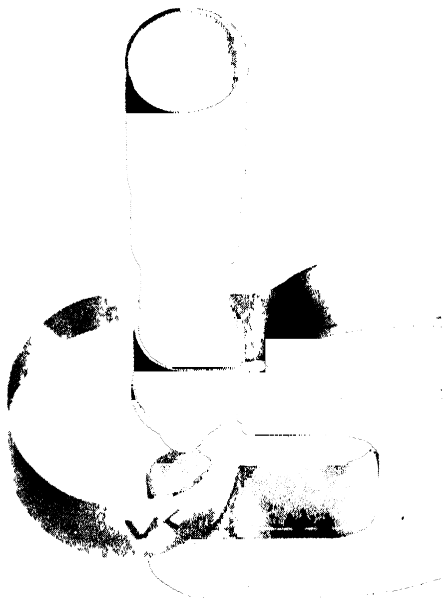


Fig. 30. Use of an optical flat to determine the measuring surface condition of a micrometer caliper.

It is a good thing, too, to examine the sharp edges of the anvil and spindle faces with a magnifying glass or fingernail to be sure nicks and burrs have not been raised from accidentally dropping the mike or rapping those sharp square edges against metal.

Checking the Zero Reading

When you are reasonably confident that the condition of the micrometer measuring surfaces are free from dirt, nicks

and surface irregularities that do not exceed .0001 inch, then check the zero reading of the micrometer. Screw the spindle down on to the anvil with standard, light, but firm pressure. Use the micrometer's ratchet device if it has one. Otherwise let the fingers slide a little over the thimble knurling, like a slipping clutch, as spindle and anvil contact. In other words translate 8 to 16 ounces pressure between your fingers to anvil and spindle faces. Above all, however, set the micrometer on zero with the same measuring pressure you intend to employ regularly with the mike in use. At that point the micrometer should read 0.

If the "zero" reading is not 0, if there is an error apparent of more than a ten-thousandth or two (.0001 inch to .0002 inch), when the measuring surfaces are closed together, then either the micrometer should be reset at its 0 station or the amount of error must be added to or subtracted from each actual measurement to be made with that micrometer — depending on which side of the 0 reading the test error falls. (Each micrometer manufacturer issues detailed, illustrated and explicit directions for resetting and correcting his instrument. Hence the omission of such instruction here.)

When the 0 test is being made, observe whether or not the spindle turns freely, in your opinion. Try to wiggle it longitudinally to see if the micrometer screw is loose in the fixed nut (see Fig. 22). Too much freedom, play, or "end shake" signifies a worn instrument, usually. The micrometer manufacturer's instructions cover the techniques for overcoming looseness.

If and when any adjustments described by the micrometer manufacturer are made, the 0 setting must be checked again.

• Calibrating the Micrometer

The next test is called calibration. Usually the test is made on a series of gage blocks of different sizes. If accurate cylinder masters — test plugs or wires — are available, or precision balls, they are frequently used for calibration checks.

A calibration test is made after the 0 setting has been assured by observing the comparison between the known size of gage block, master cylinder or ball with the micrometer barrel, thimble and vernier reading. The "mike" is calibrated at several stations. It is natural to think of testing at, say, the 1/4-inch, 1/2-inch and 3/4-inch stations on similar size gage

blocks. It is much better, however, to make up odd additions of gage blocks (or secure odd dimensions in cylinders or ball masters) such as, for instance, .195 inch, .390 inch, .585 inch, .780 inch and 1.000 inch. By some such diversification of test gage block settings, a check is secured of the condition of the spindle and nut threads (that is, of the thread lead* of the instrument) at several different points on the screw, not only along its length, but also around its periphery. Where lead errors are discovered in this calibration test that exceed .0001 inch to .0002 inch, a record should be made of them. If the inaccurate "mike" cannot be immediately replaced or repaired, its actual readings on work pieces at the inaccurate stations can be compensated for by applying the relevant calibration correction.

Lead or calibration errors appear both plus and minus. For example, the test at the .195-inch station might disclose an actual micrometer reading of .1952 inch, a plus error, which means that .0002 inch is to be subtracted from any micrometer reading on a work piece close to .195 inch. Again, the calibration at the, say, .780-inch station might read .7798 inch, a minus error of .0002 inch, and for work piece readings in the vicinity of 3/4 inch the amount of .0002 inch should be added.

Don't neglect to test or calibrate a micrometer close to the 1-inch reading. If micrometers show any errors at all, they are likely to be most marked at this end of the micrometer screw range.

An understanding of the idea or technique of "wringing" is necessary before precise micrometer calibrations can be made with flat gage blocks or masters. Study and practice in correctly wringing gage blocks together brings out this basic concept. As the spindle is being finally tightened down on a gage block, with standard pressure, the flat micrometer measuring surfaces are carefully slid a trifle laterally along the gage block surface to secure the effect of wringing. Extra care must be used, of course, where the micrometer measuring surfaces are carbide tipped, for carbide can be unmerciful in cutting or shaving the surface of an accurate gage block.

* The lead of the micrometer screw is the distance it travels axially as it rotates through one turn in the nut. When the subject of screw thread lead errors is discussed in Chapter 12, the possibility of micrometer lead errors will be more apparent.

Proper Use and Care of Micrometers

The subjects of micrometer testing, adjustment, calibration and wear brings up, of course, the need for using the micrometer properly and taking care of it when it is not in use. The idea of cleanliness has already been stressed. Micrometers should never be forced or sprung. If the principles of standard, correct gaging pressures already described are used in transferring the strength in your fingers to the pressure exerted by the micrometer spindle, there is practically no danger of springing a micrometer screw and little possibility of wearing the measuring surfaces unevenly.

When the micrometer is not in use or is to be put away, be sure it is wiped clean and free from oil, grit and sweat. Especially the measuring surfaces. And then, never leave a micrometer stored away with the spindle clamped down on the empty anvil; not even for over night. Salts, acids and alkalis in oils, cutting fluids and in sweat induce corrosion of the measuring surfaces. Such corrosion may not be at all noticeable, in the sense of visible rusting, but it converts the metal on the measuring surfaces into an impalpable powder which readily scrapes off the first time the mikes are used. The loss each time may be less than a millionth of an inch but after a while the tips of the anvil and spindle begin to resemble the conditions illustrated in Fig. 29; or the zero setting begins to show a discrepancy.

Leaving the "mike" closed seems to accentuate the corrosive action spoken of above, probably because of an additional electrolytic action taking place when the measuring surfaces are left in contact.

Learn to hold and use the micrometers correctly; the 1-inch and 2-inch sizes in one hand so that the thumb, index finger and third finger turn the spindle while the fourth and fifth fingers clamp the frame against the palm of the hand (see Fig. 31). The larger sizes of micrometers are manipulated with two hands, also illustrated in Fig. 31, or sometimes there are special measuring conditions where, even with smaller range micrometers, it is more convenient to use both hands.

Remember the principle of reference point and measured point, especially in the two-handed manipulation of micrometers. It is better to hold the micrometer anvil, which is stationary, firmly against the work with one hand and take care

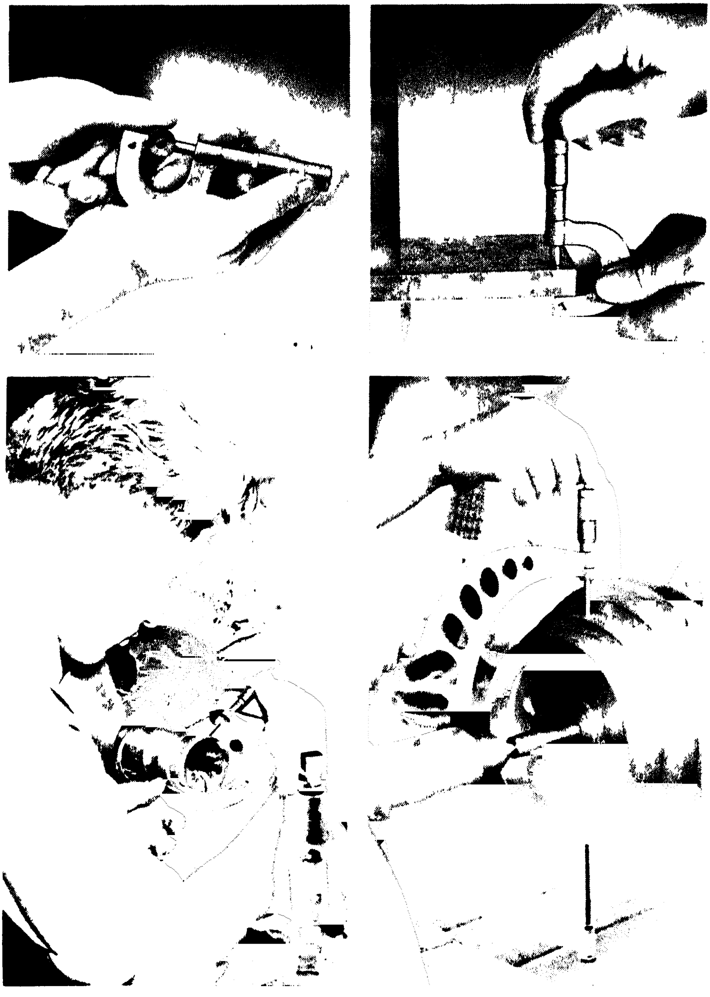


Fig 31 Correct methods of holding various micrometer calipers when making a measurement

of gaging pressure and finding the correct measured point with the other hand whose fingers turn the mike spindle.

Remember, too, that micrometers can be as readily tipped or canted as vernier calipers. This warning is emphasized here because micrometers have the knack of *seeming* to "home" readily, firmly and squarely on the work being measured. Many workers get so used to their micrometers, and

use them so rapidly, that they are not conscious of cramping them out of position on the work and of not getting, consequently, the true diameter or thickness.

One other word of warning should be issued here. While most micrometers are supplied with vernier scales, so that readings ostensibly to .0001 inch can be secured, the inspector ordinarily should not expect to measure with an accuracy or discrimination closer than .0002 inch in the ordinary use of micrometers.

A small variation from uniform finger pressure on the mike stem or the slightest — subconscious perhaps — canting or cramping of the mike on the workpiece can and will introduce an error of .0001 inch. The effect of hand temperature, too, is frequently forgotten, especially where the larger size micrometers are used. The purpose here is not to deny the micrometer's ability to measure to .0001 inch, but to warn that unless unusual care, finesse if you will, is displayed, the average user can readily mislead himself into believing he is measuring dimensions correctly to .0001 inch.

Misreading the Micrometer Scale

There is an error in reading micrometers which both the beginner and the experienced mechanic make, a form of error that seems a trifle preposterous at first thought. The neophyte makes his mistake usually in all innocence, but it is believed the expert's trouble arises more from a subconscious mental fixation than from carelessness. The mistake or error is that of misreading the micrometer barrel by .025 inch.

Look at Fig. 32. The one inch length of the barrel is primarily divided into tenths, as .1 inch and .2 inch, etc. The digit 1 shows as the primary division in Fig. 32. Then, as you know, each of the tenth divisions is again divided into four parts and each subdivision graduation represents .025 inch. Hence, in reading the micrometer setting of Fig. 32, we go through the mental arithmetic of adding two .025-inch subdivisions — which makes .050 inch — to the .1 inch main division and get .150 inch. To this we add the thimble reading of 12 or .012 inch, making .150 inch + .012 inch or .162 inch, the correct reading.

However, it is easy to misread or miscount the number of .025-inch barrel divisions uncovered by the thimble. In the case of the reading shown in Fig. 32, the inspector might

have read the barrel as .1 + .025 inch and, adding the .012-inch thimble reading, might have gotten a final, but inaccurate, reading or measurement of .137 inch. Again, he might have taken the initial barrel reading as .175 inch, rather than the correct .150 inch, and then, adding the .012-inch thimble reading, secured an incorrect result of .187 inch. In this example, Fig. 32, the latter error is probably the more likely, especially where the micrometer is dirty or the light poor, and more especially, for example, if the blue print or specification called for a dimension nearer to .187 inch than the actual workpiece measurement of .162 inch.

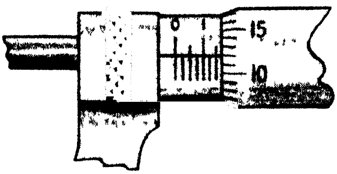


Fig. 32. Micrometer set to measure 0.162 inches.

Mechanics have been known to start off with such an error, set their machines to the incorrect size, and persist for hours in reading their mikes .025 inch "off."

The intent of some of the foregoing detail is not only to present useful information to aid the inspector in securing accurate measurements, but also because little "tricks of the trade" give a man a professional air in the performance of his duties and thus inspire additional confidence in the results of his inspections.

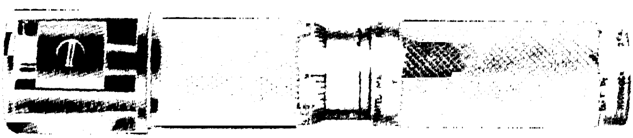
Right here should be a good place to suggest, too, that an inspector devote considerable time, during his career, to studying carefully many of the catalogues, books and leaflets furnished by the manufacturers of the various types of equipment he will be using in the normal course of his work. From such sources he will secure many valuable "professional" tips. In the same vein, the constant reading of gage and tool manufacturers' advertisements and literature keeps the inspector abreast of improvements, often revealing to him more efficient, less costly and more accurate ways of performing his work.

All of the warnings covering misuse and inaccuracies — tipping, canting, excess gaging pressure — offered in preceding sections in connection with vernier equipment apply to the special forms and shapes of micrometer apparatus. The use of an inside micrometer with extensions offers an excellent object lesson in reference point, measured point, centralization, tipping, canting and gaging pressure.

Micrometer Plug Gages

Thus far, in this chapter, the only devices described for measuring hole and bore diameters have been calipers and vernier calipers. During the years, several other means have been developed for this purpose, apparatus and instruments that are essentially variations of or accessories for basic measuring equipment.

So-called "inside" micrometers can be secured. One type is the micrometer plug gage shown in Fig. 33. Three blocks or



Courtesy of Taft Peirce Mfg Co

Fig. 33. Micrometer plug gage.

guides make up the solid frame of the gage. Between the guides are three movable members or blades which are seated directly on a hardened cone ground to an exact angle. A micrometer screw mechanism, with thimble and barrel, is attached to the solid framework of the guides, and the hardened cone, in turn, is the tip of the micrometer screw or spindle.

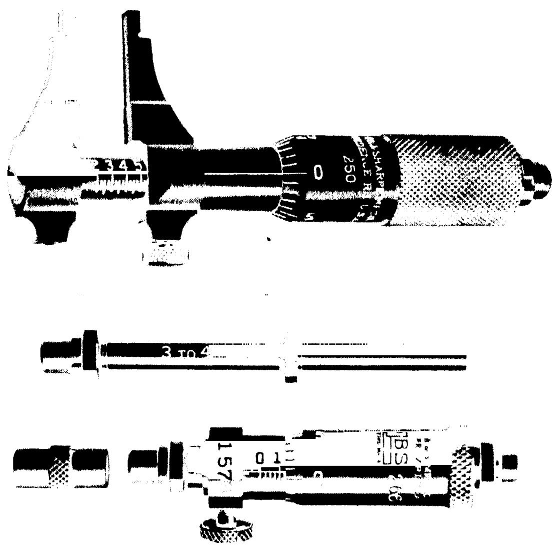
As the micrometer plug gage is introduced into a hole, the thimble and spindle are turned. The cone, travelling forward, then expands the blades against the sides of the hole. While barrel and thimble markings measure essentially the lateral travel of the cone, they are actually marked and calibrated so that the cone travel and, consequently, the expansion of the

blades, are literally translated into direct diameter readings in thousandths of an inch. Each such micrometer plug gage is nearly single-purpose in that its range of operation is confined to any 1/16-inch step in diameter. Gages of this type can be furnished in all sizes from 3/4 inch to 4 inches in 1/16-inch steps. In other words, one gage must be used, for example, for a 15/16-inch general hole size and another for 1-inch holes, etc.

Brief mention of this type of bore gage is made here in order to introduce a word of warning. In using it, an inspector may well *not* get the exact measurement to .001 inch he anticipates except with care. As the micrometer thimble is turned and the blades are forced against the hole sides, the blades may not "home" correctly. The gage should be rocked a little as the blades are homing. Then, a second or check reading should always be made to be sure of a repeat reading because the expanding blades also have a tendency to "creep."

Inside Micrometers

Considerably more versatile are the inside micrometers illustrated in the top illustration in Fig. 34. Anyone who has prop-



Courtesy of Brown & Sharpe Mfg. Co.

Fig. 34. (Upper) Inside micrometer caliper. (Lower) Inside micrometer with extension spindles to increase range of measurement.

erly used micrometers and inside vernier calipers will see readily how the inside micrometer caliper of Fig. 34 is used. Needless to say, this sort of instrument must be checked regularly for 0 setting and for bent or worn caliper tips. The usual rules for rocking it and centering it on the true diameter, for standard gaging pressure and for repetition (repeat reading) tests also apply, of course. These instruments have a range commonly to cover the measurement of internal diameters from .200 to 1 inch.

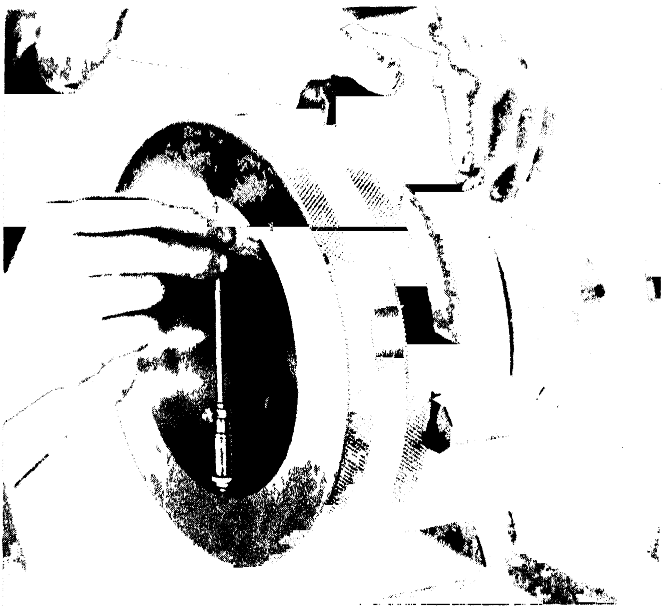
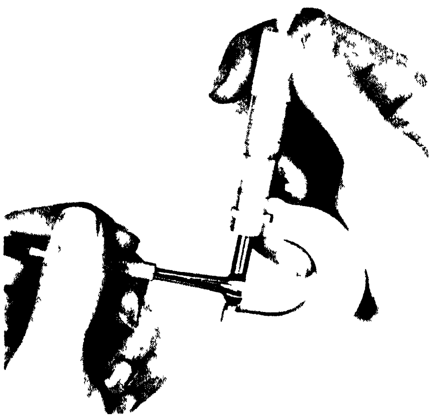


Fig. 35. Inside micrometer shown in lower view of Fig. 34, being used to measure a bore.

The inside micrometer sets like that in the bottom illustration in Fig. 34 can be secured in a variety of range groups so that bores anywhere between 1 and 36 inches can be measured to an accuracy of .001 inch. Closer study of this illustration will show that the instrument is basically a micrometer — screw, barrel, thimble — with a very short spindle. The spindle also contains a chuck in which the various extensions can be fastened. The No. 1 extension adds an inch in length to the micrometer and each successive extension in the series is 1 inch longer than its predecessor.

Figure 35 not only portrays an inside "mike" in use but emphasizes the ideas of reference point, measured point and centralization. In addition to taking the usual measurement precautions, the inspector should watch for two causes of inaccuracy when using this form of inside mike. The extensions must be butted securely in the micrometer and extension sockets. Even the slightest inattention to this point can produce errors of several thousandths. He must also be careful not to use the extension inside mike too long. The temperature of the hands can warm it up and expand the extension rapidly enough to produce significant errors.

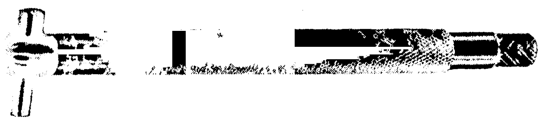


Courtesy of The L S Starrett Co

Fig. 36. One type of small hole gage being measured after setting to determine the hole size.

Split-sphere and Telescope Gages

Ball shaped small hole gages will be found in most gage cabinets. As Fig. 36 indicates, these gages consist primarily of split hollow spheres the halves of which can be expanded within a hole by means of a knurled knob which turns a screw thread that forces a spreader between the sphere halves. When the gage spheres have been set by applying standard gaging pressure to the knurled knob and by the feel of the split spheres within the hole, the gage is removed and the diameter of its spread sphere measured with a micrometer as in Fig. 36. This is an adaptation of measuring over the points of standard inside calipers as illustrated in Fig. 11.



Courtesy of Brown & Sharpe Mfg Co

Fig. 37. Telescope type gage for measuring hole diameters.

A bigger brother of the split-sphere, small-hole gage appears in Fig. 37, the telescope gage. One leg of the T is solid, the other leg telescopes into it. The telescoping leg is spring loaded. The knurled screw knob at the other end of the gage, in this case, turns a locking screw which will lock the telescoping leg in any position or length it may assume inside the hole being measured.

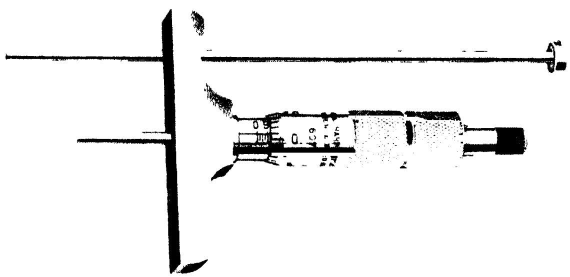
Courtesy of Brown & Sharpe Mfg Co

Fig. 38. Three-point gage for measuring internal diameters. Design facilitates correct centralization and alignment for accurate measurement.

Another design of gage for bore or hole measurement has three measuring points, each of which is designed to make line

contact with the surface of the hole. Thus it can be readily centralized and aligned for accurate measurement of the true bore diameter. Extensions permit measurement of deep bores or holes and a micrometer-type scale permits direct reading. Various sizes are available to measure up to 4-inch internal diameters. Figure 38 shows this gage in use.

Enough has been said heretofore in regard to gaging pressure and the positioning of calipers, as well as the proper use of micrometers, so that the inspector should be able to get precise readings. In a sense, double caution is required because there is the need of properly using the T or ball gage and then of properly using the micrometer. In this type of measurement on close tolerances it is certainly best to repeat each measurement and reading. If you get repetition (repeat readings) you are probably measuring accurately; if not, you had better try again. Even so, with considerable care, measurements with a discrimination or accuracy better than .0005 inch are difficult to get.



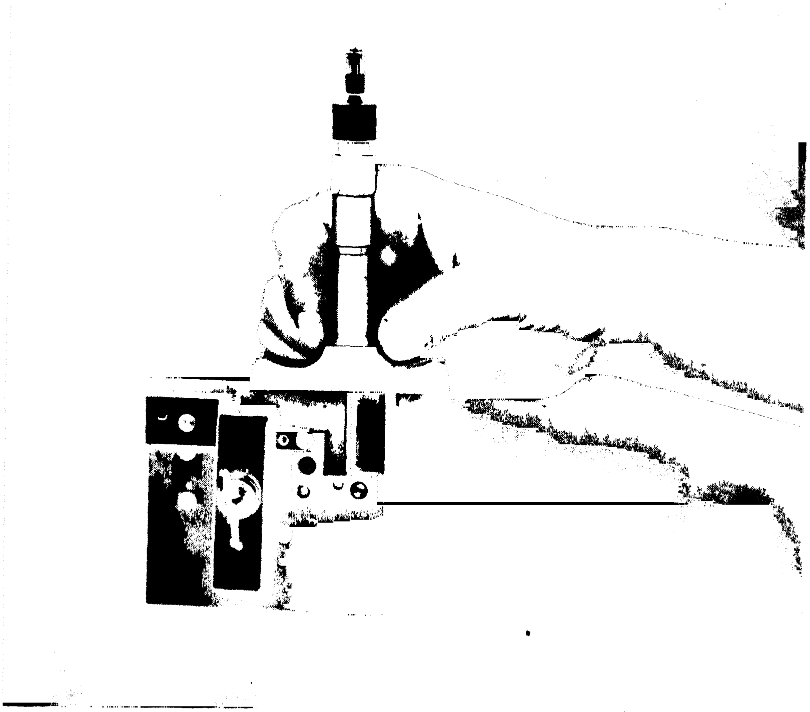
Courtesy of Brown & Sharpe Mfg. Co.

Fig. 39. Micrometer type depth gage and auxiliary long-length spindle.

Micrometer Depth Gage

Another common form of micrometer equipment is the micrometer depth gage illustrated in Fig. 39. One thing especially is to be noted concerning it as an instrument. The graduations on the standard micrometer caliper start at 0 when the thimble and spindle are screwed in to the fullest extent (when the micrometer jaws are closed) and as the micrometer is opened, as the thimble backs away, the readings of 1 (0.1 inch), 2 (0.2 inch), etc., are exposed. The graduation

readings on the barrel of the depth micrometer are, however, reversed. When the thimble is screwed way down and the graduations are fully concealed the stem of the depth micrometer has been screwed *out* 1 inch, screwed out to its fullest extent. As the thimble is unscrewed the digits 9 (0.9 inch), 8 (0.8 inch), etc., see Fig. 39, become uncovered. The stem is receding toward the base, of course, and at the micrometer 0 reading the stem is fully receded, though the thimble and screw have been turned all the way out. Figure 40 shows a depth micrometer in use.



Courtesy of Brown & Sharpe Mfg Co

Fig. 40. Depth gage being used to measure the location of a block.

A simple way to check the accuracy of a depth micrometer appears in Fig. 41. Unscrew the spindle and set the base of the mike on a flat surface like a surface plate or toolmakers' flat as shown at the left in Fig. 41. Holding the base down firmly turn the thimble or screw in, or down, and when the tip of the mike depth stem contacts the flat firmly, with not

Courtesy of The Lufkin Rule Co

Fig 41 Method of checking the accuracy of a depth gage: (Left) Zero reading being checked by using a surface plate. (Right) 1-inch reading being checked using a 1-inch gage block and surface plate.

more than two pounds gaging pressure, read the barrel. If the mike is accurate, it should read 0. Then rest the mike on a 1-inch gage block, as shown at the right in Fig. 41, and screw the stem all the way down to contact with the flat. There it should register 1 inch.

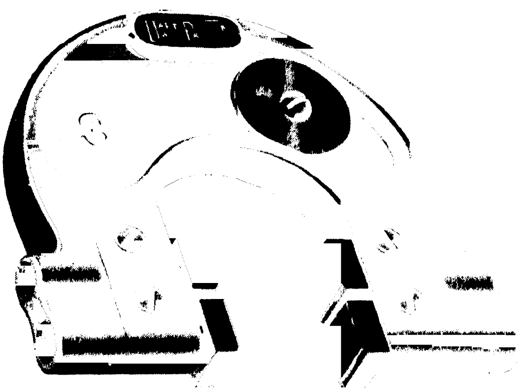
The warnings previously given for vernier depth gages also apply to micrometer depth gages.

CHAPTER 6

Fixed Gages

Basically, fixed gages are designed and made to measure a single dimension, though many so-called conventional gages are equipped for adjustments over a limited range.

In general, there are several recognized types of fixed gages. For O.D.'s (outside diameters) and thicknesses, or similar measurements, there are snap gages and ring gages. For holes, I.D.'s (inside diameters), slots and similar measurements, there are plug gages and feeler gages. Fixed gages take on special shapes such as taper gages, spline gages, length gages and depth flush pin gages. Fixed gages are also classified as single purpose, progressive, double end or reversible.



Courtesy of Taft Peirce Mfg. Co.

Fig. 1. Snap gage with provision for adjustment over a limited range.

Using the Snap Gage

The snap gage is essentially a fixed caliper, although, as shown in Fig. 1, there may be provision for a limited range

of adjustment. The rules that apply to calipering should be observed when using conventional snap gages, plus one or two extra admonitions which relate to the peculiarities of a snap gage.

Probably the most common, but incorrect, tendency in using a snap gage is simply to slide it over the work like slipping the claws of a carpenter's hammer over the shank of a nail you want to pull. To slip a workpiece between the jaws or anvils of a snap gage the way you back a horse between the shafts of a carriage is not necessarily measuring. In using a snap gage never forget for a minute the conception of the reference point and the measured point.

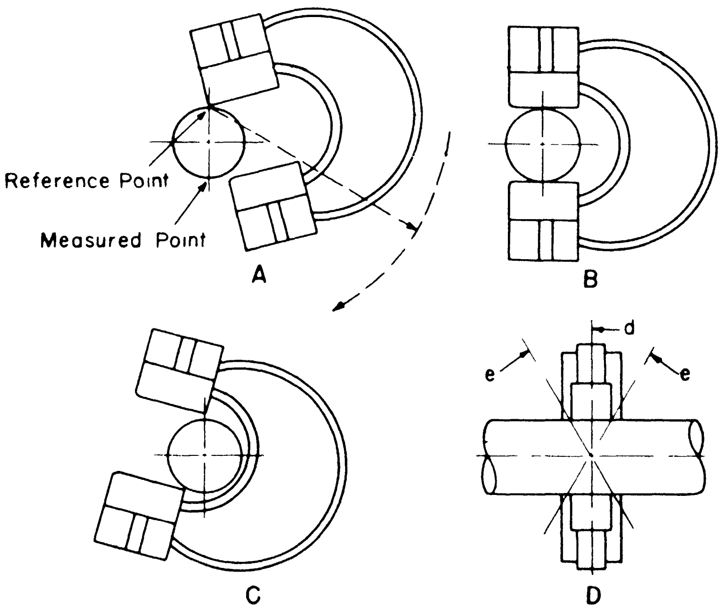


Fig. 2. Method of applying snap gage to work-piece: (A) First step. (B) Second step. (C) Result of pushing the gage too far onto the work. (D) Correct measurement is along line *d*, not along lines *e*.

First rest the upper anvil as a reference point on the work-piece and then swing the gage, the upper anvil acting as a hinge or pivot, and measure with the lower anvil as suggested in sketch A of Fig. 2. The complete and true check is considered technically completed when the anvils cover the true

diameter of the workpiece equally as shown at B in Fig. 2. True measurement may not be obtained where one anvil has not been brought up fully, as sketch A in Fig. 2 shows, or an equal error may be made where one anvil of the gage is pushed too far — see C of Fig. 2.

Considerable care must be used, too, not to cant or tip the gage. The plane of the gage should be, of course, perpendicular to the center line of the work, after the manner shown at *d* in sketch D of Fig. 2, so as to prevent the possibility, shown somewhat exaggerated, of measuring false diameters like *e* and *e*. Such warnings seem superfluous, but it is surprising how casual, careless and hurried the average worker becomes with a snap gage, especially under the pressure of commercial production.

Because the average commercial type of snap gage feels heavy, rugged and solid, there is a natural tendency to use it as a sizing tool. The rigidity is built into this type gage purposely to prevent its warping or springing; to offer, in other words, error-proof measuring equipment. As a consequence, extra care or restraint must be practiced in order to apply no more than the standard gaging pressure of a pound or so when calipering with it. One system of standard gaging pressure recommended by some shops makes use of the natural dead weight of the average commercial snap gage, a system under which the inspector is instructed to let the gage slide over the work of its own weight without additional hand pressure as a criterion of dimensional conformance.

The snap gage may be applied to the work in the machine, or the gage may be gripped in one hand and the workpiece fed into it. A more efficient alternative may be where the snap gage is mounted in a bench stand and the workpieces can be applied alternately to it with both hands.

The Fixed Snap Gage

Another conception should be kept in mind when using snap gages. The fixed gage, as a type of measuring apparatus, is frequently termed a limit gage. It does not measure in the sense of a graduated instrument like a vernier caliper or a micrometer, offering the more or less exact size of the workpiece. The snap or fixed limit gage simply states that the work is within a certain tolerance, or it is larger or smaller than the required specifications — assuming, of course, the gage is properly set and not worn.

Usually, then, the fixed gage offers two steps of measurement — one pair of calipers for the high limit of size and another pair for the low limit. (A very few fixed type of commercial gages offer only a single size limit, see A in Fig. 3). The high and low steps may be two separate calipers at opposite ends of the gage, as at B in Fig. 3, though more usually the construction offers "progressive" measurement of succeeding calipers in line with each other as illustrated at C.

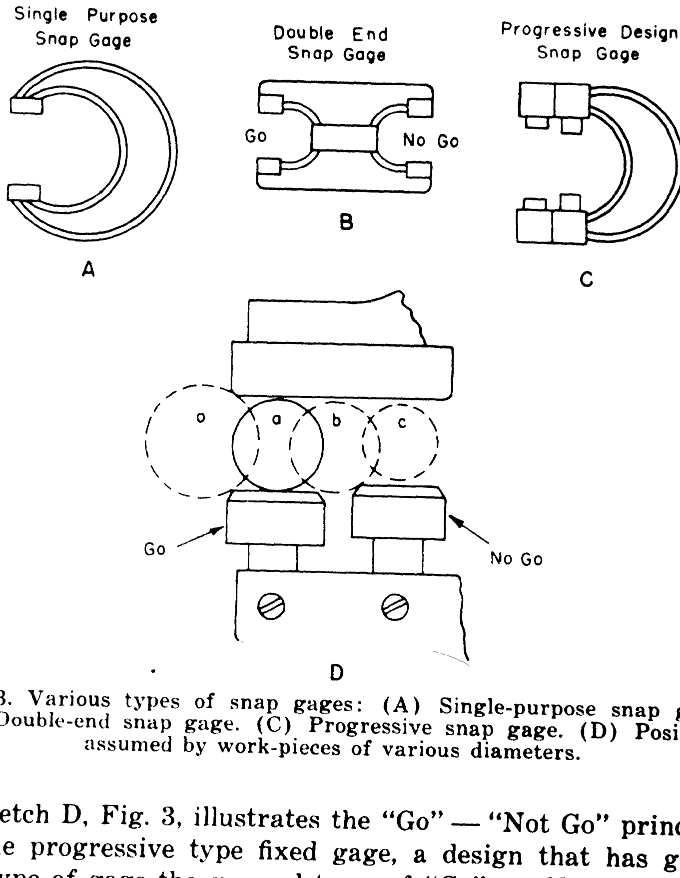


Fig. 3. Various types of snap gages: (A) Single-purpose snap gage. (B) Double-end snap gage. (C) Progressive snap gage. (D) Positions assumed by work-pieces of various diameters.

Sketch D, Fig. 3, illustrates the "Go" — "Not Go" principle of the progressive type fixed gage, a design that has given the type of gage the general term of "Go" — "Not Go" gage.

If the workpiece is of such size it can enter the "Go" end of the gage as at *a* in sketch D but not enter the "Not Go" part of the gage as at *b*, it is within tolerances if the gage has been properly set. (Some refer to the "Not Go" section of the gage as the "No Go" limit.) In other words, work that is

within specifications must go in the "Go" section of the gage but it must not go in the "Not Go" section.

Where the workpiece is too small it will enter the "Not Go" caliper — see position *c* in sketch D of Fig. 3 — and is consequently rejectable.

Another equally relevant "Not Go" condition is illustrated by the oversize diameter of the workpiece at position *o* (sketch D of Fig. 3), which therefore prevents its entering even the first or "*Go*" step of the gage.

It should be clear at this point that, for the worker or inspector who will use a fixed gage, the gage is "fixed" so far as size measurement is concerned. Hence, the first natural question should be: are the "Go" — "Not Go" calipers set to the proper size?

Earlier in this book the inspector was warned to question the authority of any blue print or specification. A later section cautioned him to check the accuracy of micrometers before using them. He should be in the same frame of mind, before he uses snap gages. Frequently the "Go" and "Not Go" limits for a particular use of the snap gage are stamped on its frame. What authority is the source of these figures? Is the gage set exactly to them? Have the gaging surfaces become worn? Does the gage setting correspond with similar figures on the product blue print?

In many shops, the snap gage adjusting screws are covered with sealing wax, after the gage has been correctly set, and in those same shops the rule has been made that no snap gage is to be used if the sealing wax over any adjusting screw is missing.

Checking the Snap Gage for Accuracy

It is such a simple matter to check the accuracy of a snap gage and the parallelism of its jaws, that either the occasional or prolonged use of an inaccurate gage is inexcusable.

In checking a fixed snap gage, as shown in Fig. 4, precision gage blocks are used, but master cylinders or discs would be equally successful. Have one set of blocks set up for the prescribed "Not Go" limit of the gage (or a suitable diameter cylindrical master) and another set of blocks for the "Go" section. If the gage is properly set, the "Not Go" gage blocks should just enter between the "Not Go" jaws, perhaps with a slight wringing fit, but no more than two pounds finger

pressure should be necessary. The same sort of test applies to the "Go" section. Be sure, of course, that the gage blocks are not unconsciously tipped, canted or cramped. Before using the gage blocks, see that the snap-gage anvils are free from dirt, grit, edge nicks or burrs that would either prevent the gage blocks from sliding between the anvils or scratch or cut the gage blocks.

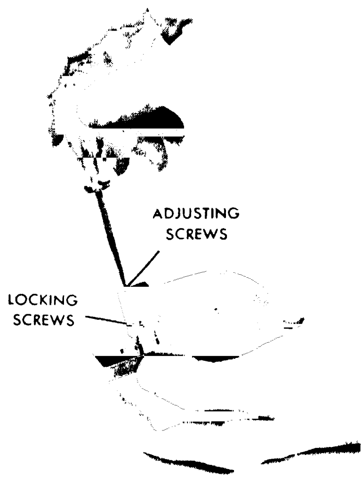


Fig. 4. (Left) Using gage blocks to check the "Go" and "Not Go" settings of a snap gage. Fig. 5. (Right) Adjusting a snap gage to the required "Go" and "Not Go" settings.

If the snap-gage anvils are not properly set — the gap between them may be too wide or too narrow, as shown by the gage block test — loosen the locking screws, as shown in Fig. 5, and unscrew the adjusting screws a turn or so. Push the anvils, the stems of which will slide in their sockets when the locking screws are loosened, against the adjusting screws thus opening the snap-gage anvil gap a trifle. Put the gage blocks in between the anvils and screw down on the adjusting screw with not more than the standard two pounds gaging pressure. Tighten the locking screw and check the gap with the gage blocks.

Factors to Consider in Setting the Adjustable Snap Gage

In the case of truly fixed snap gages, the non-adjustable, single-purpose gages like those illustrated in sketches A, B and C in Fig. 3, gage maker's tolerances and gage surface wear allowances permit some variation in their size. Like any other worker, the gage maker cannot necessarily produce a gage to an exact size. He must have some latitude or tolerance. Usually the gage maker's tolerance is combined with the so-called wear allowance. This latter governs the allowable change in size due to wear of the gaging surfaces.

One common rule of thumb sets this combined tolerance at 1/10th, or 10 per cent, of the tolerance spread of the specification for the work the gage is to be used on. As an example, suppose the gage is bought for .837 inch ± .001 inch work. The tolerance spread of ± .001 inch is .002 inch. One-tenth of .002 inch is .0002 inch. Hence, likely, the new gage would not be made to measure .838 inch, the largest size piece allowable under .837 inch ± .001 inch tolerances, but at .838 inch minus .0002 inch or .8378 inch. Closing in the jaw gap by .0002 inch allows the gage to wear back in use to the full .838 inch. In some plants this sort of wear is permitted beyond the maximum, as, for instance, to .8382 inch — a total of .0004 inch wear. (In the case of adjustable snap gages, the so-called gage makers' tolerance is usually equal to the wear allowance. In this case, .0001 inch would be called gage makers' tolerance and .0001 inch wear alowance.) Because of the practice, and necessity, for recognizing and having gage makers' tolerances and wear allowances, the gage, in use, may at any time accept or reject work which is a tenth or two (.0001-.0002 inch) either side of the exact tolerance or specification.

Hence, in setting, adjusting or calibrating the step or adjustable type snap gage (Fig. 1) the idea of wear tolerance should be kept in mind of course. The inspector can determine what his shop's standards are in connection with this somewhat controversial subject and apply the required tolerances at his gage setting.* If his shop has no established practice, the 10 per cent rule mentioned above will likely be found practical.

* The suggestion has been made previously that the inspector secure relevant publications from the American Standards Association, 70 E. 45th St., New York. Information on American Gage Design (A.G.D.) standards, such as wear and makers' tolerances, can be secured from the same source.

To reduce the error due to wear in adjustable and single-purpose snap gages the normal hardened steel anvil surfaces are hard chrome plated, a very satisfactory addition. Worn surfaces of fixed, single-purpose gages can be built up with chrome plate and then fine ground and lapped to final precise size. Where snap gages get steady and prolonged service, and especially if they have to be used in the presence of grinding grit and the like, it pays to have the anvils tipped with carbide, Norbide or sapphire. Chrome plating will increase wear life of gage anvils five times; carbide anvils last ten to a hundred times longer.

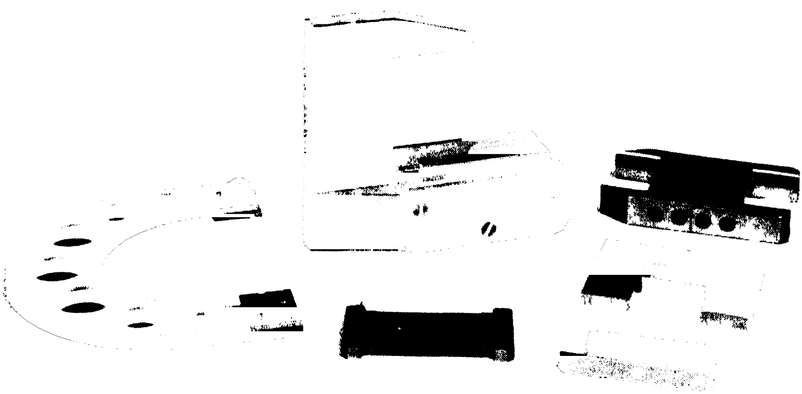


Fig. 6. Snap gages of special design.

Fixed snap gages are made not only in the conventional, more or less universal shapes of portable hand gages illustrated thus far, but they can also be obtained in special shapes and forms for definite purposes in both portable and bench models. Fig. 6 pictures a few special designs.

The C-shaped snap gages are useful too, of course, in checking flat stock or thickness and width of rectangular pieces, as well as on cylindrical work.

Ring Gages

For limit measurements on cylindrical components, the ring gage is widely used. Several ring gages of standard design are shown in Fig. 7. The "Go" — "Not Go" limit principle is

obtained by using a pair of rings — the "Not Go" ring distinguished from the "Go" ring by an annular groove cut in the former's outer knurled surface. For greater convenience, ring limit gages are frequently paired as hardened bushings inserted in a single steel plate.

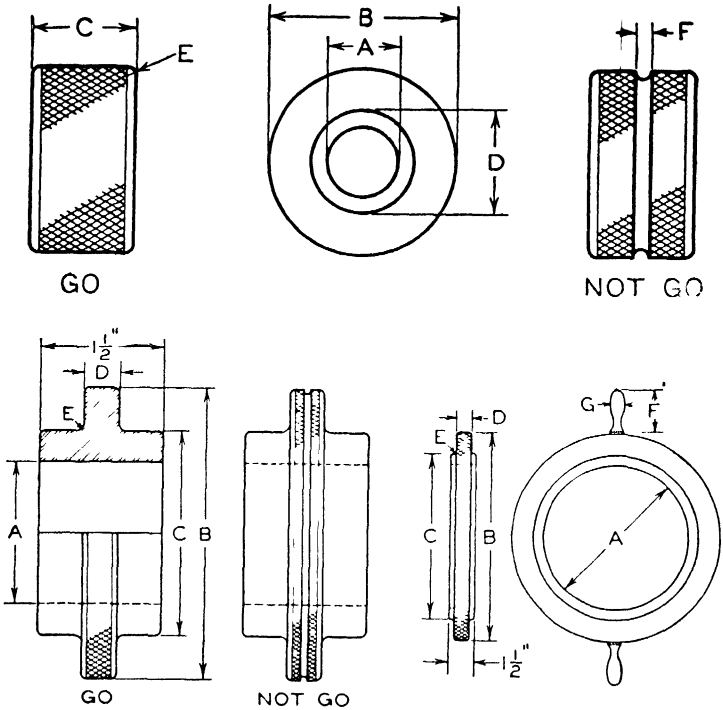


Fig. 7. Ring gages of standard design.

In general, ring gages are used in the manner pictured by Fig. 8. The same universal rule for gaging pressure applies, the finger tips exerting from one to two pounds pressure. The strong human tendency, of course, is to force the workpiece through a ring gage and this inclination must be sedulously overcome if anything like a true limit check is to be obtained.

For decades, a rather practical viewpoint has been held in many shops that if shafts, for instance, are to be turned to fit certain size bearings or holes, the best gage is a mating part. You will see this traditional practice prevailing in a few shops today — a sample bearing or a component with a hole

in it hung on a nail or wired to the lathe. While ring gages carry out the same general mating part principle, they are much more accurate and reliable. Unlike the mating part hanging on the wall, they are made to precise tested sizes and have hardened surfaces, that prevent wearing oversize too quickly.

Fig 8 Using a ring gage to check the over-all outside diameter of a work-piece.

Gage Makers' Tolerance and Wear Allowance

Anyone manufacturing a solid, non-adjustable instrument such as a ring gage or a single-purpose, fixed snap gage like that shown in Fig. 3, faces the question of gage makers' tolerance and wear allowance. The gage makers' tolerances shown in the following table were established by the American Gage Design (A.G.D.) Committee and have been widely used. It will be noted that there are five tolerance classes: XX, X, Y, Z, and ZZ.

Plug and Ring Gage Tolerances — American Gage Design Standard

Nominal Size — Inches Above	To and Incl.	(Male Gages Only) XX	X	Y	Z	(Ring Gages Only) ZZ
.029 —	.825	.00002	.00004	.00007	.00010	.00020
.825 —	1.510	.00003	.00006	.00009	.00012	.00024
1.510 —	2.510	.00004	.00008	.00012	.00016	.00032
2.510 —	4.510	.00005	.00010	.00015	.00020	.00040
4.510 —	6.510	.000065	.00013	.00019	.00025	.00050
6.510 —	9.010	.00008	.00016	.00024	.00032	.00064
9.010 —	12.010	.00010	.00020	.00030	.00040	.00080

XX — Precision lapped (plugs or male masters only)
X — Precision lapped plugs or rings
Y — Lapped plugs or rings
Z — Ground and polished (grinding marks may be in evidence)
ZZ — Ground only (for rings only)

The table can be best understood, perhaps, by studying one range of sizes like the 1.510- to 2.510-inch category for instance. In this range of ring gages, the gage makers' tolerance is to be confined to .00008 inch if a Class X gage, so-called, is purchased. This means that the hole in the brand new gage will usually be .00008 inch smaller than the basic size. It may be, legally, .00008 inch larger.

On the other hand, the tolerance for a Class ZZ gage is .00032 inch, an allowance four times greater than the Class X limit. The difference is a matter of cost and, consequently, price of the gage. If ordinary, quick measurements are to be made on fairly rough commercial work whose blue print tolerances range from ± .001 inch to ± .010 inch, say, there is no need of paying a premium for Class X gages. If, however, precise control to something like .0001 inch or .0002 inch is required on fine machine work, the Class X gages are necessary.

The tolerances listed in the table above cover the gage makers' tolerances. The usual custom, in ordering or making a gage or in setting an adjustable snap gage is to add a wear allowance. Suppose a basic dimension for a gage or gage step is to be .852 inch. The standard gage makers' tolerance would be .00006 inch (Class X). Hence, a ring gage might actually have an internal diameter of .85194 inch or .85206 inch. Normally, an additional .00005 inch or .0001 inch would be allowed for wear. Taking, say .0001 inch for wear allowance out of the ring gage internal diameter would give an actual, new ring gage size of either .85184 inch (.85194 inch − .0001 inch)

instead of the basic .852 inch, or it would give .85196 inch (.85206 inch − .0001 inch), depending on which side of the *basic* dimension the gage maker happened to take his tolerance. Of course, it would be in between .85184 inch and .85196 inch if the gage maker only took part of his allowable tolerance.

In studying the foregoing, notice, too, that the gage makers' tolerances increase materially as the size of the gage doubles, trebles or quadruples. The reasoning behind this is that it is more difficult for the gage maker to maintain fine precision on the larger sizes; that, similarly, the lathe worker or grinder hand will have equal difficulty on larger diameter workpieces; that the larger rings, being heavier and bulkier, will wear faster; and, finally, that temperature has a more direct effect in measuring larger diameters.

In some shops, the various classes of gages are used in the following manner. The machinist, for instance, is supplied with a Class ZZ or Z gage. The inspector uses the somewhat more precise Y class gages and the Class X gages are kept as masters for final reference in case of dispute. Basically, all this goes back to using gages of finer discrimination where greater discrimination is needed.

The proper classification of gages (X, Y or Z, etc.) to use can be determined by the 10 per cent rule. If the workpiece dimension is 2.938 ± .002 inches so that the total tolerance or tolerance *spread* is .004 inch, for instance, a Class ZZ gage would be adequate. 1/10th of .004 inch is .0004 inch. See 2.510-inch to 4.510-inch range in table on page 128. On the other hand, a Class X gage would be needed where the specification allowed only .001-inch tolerance spread. (1/10th of .001 inch is .0001 inch and in this table, size range 2.510 to 4.510 inches calls for .0001 inch gage tolerance in Class X).

Limitations of Ring Gages

Ring gages indicate over-all size limits on cylindrical workpieces. They tell little else about the work. They will accept out-of-round work without a qualm provided the largest diameter of the piece is within bounds, see exaggerated case at A in Fig. 9, although such work may not help to make a satisfactory assembled product. Ring gages can detect excessive taper, as illustrated at B in Fig. 9, although where the largest diameter is still within limits the worker is very prone to "pass" it. These are some of the pitfalls in ring gaging. Ring gages

present also the disadvantage that work must be taken out of the machine, ordinarily, and be deburred before an effective check can be made. To an extent then, the C-shaped snap gage is somewhat more useful.

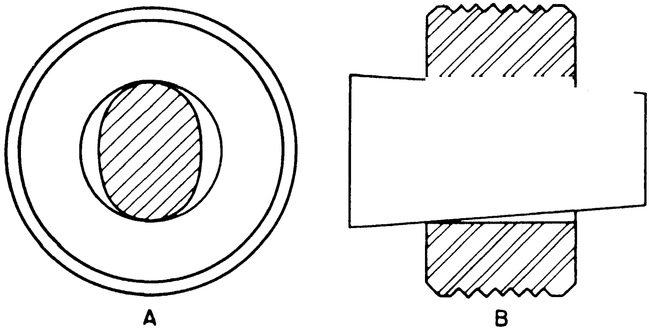


Fig. 9. (A) Ovality in the shape of a work-piece cannot be detected by a ring gage. (B) Excessive taper in a work-piece can be detected by a ring gage.

One definite recommendation for ring gages must be mentioned, however. In a previous section the triangle effect on pieces coming from centerless grinders has been described. Unless the factory has available indicating, electric or air gaging equipment specially designed for detecting the degree of triangle effect, ring gages are the only means of truly checking the limiting sizes of cylindrical pieces bearing the triangle error. Micrometers, snap gages or any type of two-point, caliper measuring equipment will not reveal the "mating" or greatest effective diameter of work in which the triangle effect appears. (The "mating" or effective diameter of a triangular or oval shaped workpiece is the diameter of the hole into which the piece will fit.)

Plug Gages

The idea of a mating piece has been mentioned above, a ring gage being essentially the "mating" hole for cylindrical pieces. Plug gages are based on this same general concept. Is a hole the right size? One way to check it is to try in it the shaft or cylinder of the proper diameter that is to mate with it. Another way, of course, is to check the hole diameter with a more precise, non-wearing member, a cylinder called a plug gage.

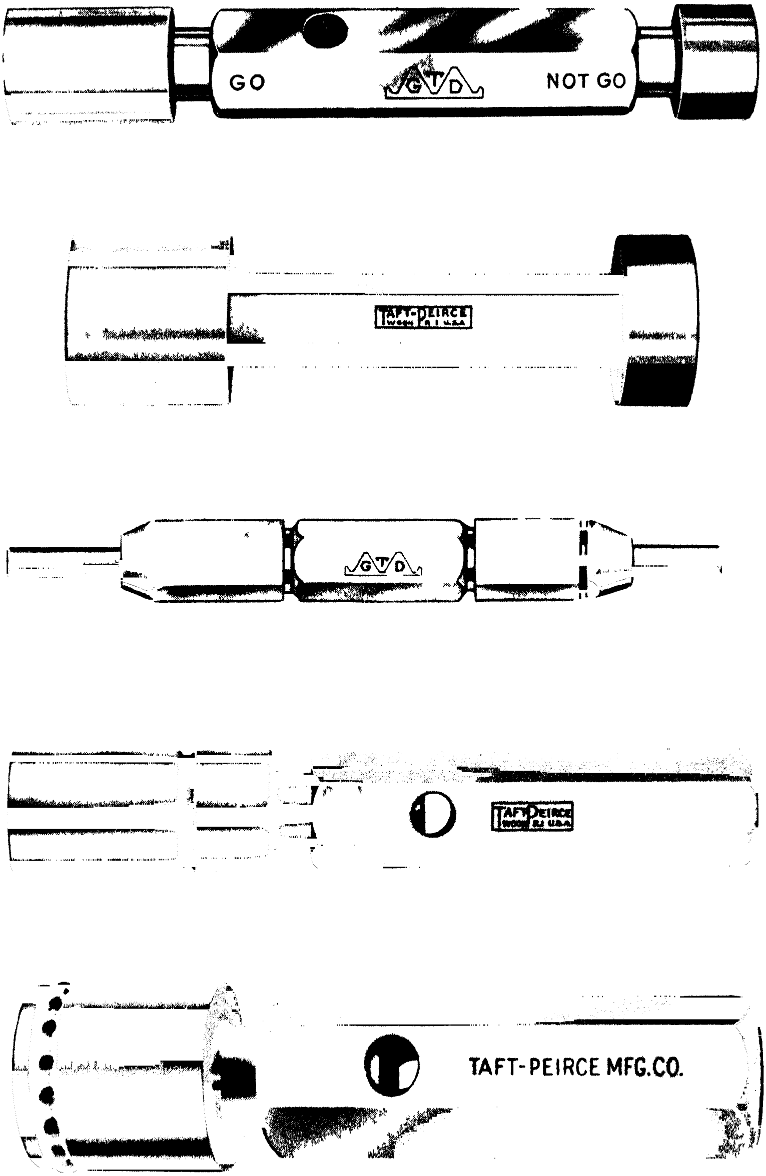
For the sake of illustration, several varieties of commercial plug gages are pictured in Fig. 10. The average commercial plug gage is a precision ground, hardened cylinder somewhere around an inch long. Plug gages usually come in pairs and are gripped in hexagonal holders. Reversible plug gages, so-called, have a "Go" plug in one end of the holder and a "Not Go" plug in the other. The "Not Go" plug is frequently made shorter in length purposely to distinguish it more readily from the go plug. The specification limits are usually stamped on the holder. Figure 10 shows also a progressive, stepped type, which is faster to use than the reversible or double-end "Go" — "No Go" gage, but has the disadvantage that both sections must be replaced when the "Go" section, which usually gets the greater use, becomes worn down. Some plug gages are really steel wires, they are so small in diameter; others are large enough to require both hands to lift and manipulate them. As in the case of snap gages, plug gages frequently come chrome plated or in carbide or Norbide. Unlike conventional snap gages, they are inevitably single purpose — no adjustment whatsoever can be provided — a proper diameter plug being required for each tolerance or specification.

Plug gages are furnished in the X, Y, and Z classifications for precision and finish. If you will note the table on page 128 closely you will see that tolerance specifications in the XX class are for plug gages only and that plug gages are not ordinarily furnished in the ZZ class.

Proper Use of Plug Gages

There is a trick to using plug gages if you want to get precise measurement. Too many people use them for hand reamers. Or crowbars. (Workers have been seen pounding in nails or hammering up lathe dog clamps with them). Let the punch, drill, reamer, broach, or boring tool cut the hole; use a plug gage only to measure the resulting size. If you will handle a plug gage in somewhat the same manner you do a pencil you will come nearer to the true measurement than if you try to expand the hole to size.

It might be well to digress here and enlarge on a human foible implied in the last sentence of the paragraph above. What is involved is probably wishful thinking. Skilled mechanics and neophytes seem to be equally guilty. There is a strong



Courtesy of Greenfield Tap and Die Corp
Courtesy of Taft Peirce Mfg Co

Fig 10. Various types of plug gages.

tendency to "make" (using shop language) the workpiece "come" to the size you want it to. This, rather than to let the gage do its own work unhampered and measure the actual dimension of the workpiece. If the blue print, as an example, calls for .375 inch – .001 inch, + .002 inch and if the workpiece is actually, say .373 inch, you are quite likely to manipulate micrometers, verniers or fixed gages either by subconsciously increasing the gaging pressure or lightening up on it so that somehow you get the .374-inch reading or convince, "kid," yourself that you do. Indicating equipment, as will be seen from the description and discussion of it farther on helps to eliminate this form of error or unintentional dishonesty.

Go back to the "measured point" conception. Consider a plug gage essentially as inside caliper points on opposite sides of a true diameter. The remainder of the plug gage cylinder can be considered as a skirt or guide. All the rules concerning manipulation discussed in previous sections apply to plug gages.

Many makes of plug gages are equipped with pilot tips (see Fig. 10) to facilitate inserting the plug and prevent the shaving action of sharp-edged gages. A plug gage, it goes without saying, should be kept clean and it should be used only on clean work. Any small amount of dust, grit or chips is especially merciless on plug gages. The plug surfaces should be coated always with a film of oil.

One Difficulty to be Avoided

The green inspector is liable to run into one embarrassing experience with plug gages. If he is gaging a fairly deep hole — something more than a half-inch deep, perhaps; if the hole diameter happens to be right at specification size and consequently at the same size practically as the plug gage diameter; if both gage and workpiece happen to be dry — free from grease; then practically metal to metal contact is secured as the gage is forced into the hole and, if the inspector is stubborn enough to continue using undue pressure, the gage will "freeze" in the hole. The harder he pushes or pulls or twists to get it loose, the tighter it sticks. Dislodging the gage may mean rapping it, resorting to a vise or even to heating the workpiece to expand it away from the gage. Where you are aware that the measurement with a plug gage might bring about this freezing, be sure the gage surface is oil

coated and be sure especially, to use the words of experienced mechanics, "to keep it moving." Once you stop the motion, the workpiece may lock onto the gage. The danger of a gage freezing on the work also applies to ring gages.

Checking the Plug Gage

Before using a plug gage, the inspector should question first the authority for the "Go" and "Not Go" sizes stamped on the gage. Do they correspond to the blue print tolerances? Then, of course, the actual diameter of the plugs should be carefully measured to be sure their actual diameters check with the size markings on the gage.

Note that, in contrast to a snap gage, the "Go" end of a plug gage has the smaller diameter. The "Not Go" end is larger. If a hole is so large that not only the "Go" plug enters but also the "Not Go" end, the hole is out of tolerance because it is oversize. If the hole is so small that the "Go" end plug will not enter it, the hole is out of tolerance in the sense of being undersize. The correct size hole will receive the "Go" plug but not the "Not Go" plug.

If the end of the gage has a square edge — if it is not equipped with a pilot in other words — check the edge with your finger nail for fine nicks and raised burrs. Of all gages and measuring equipment, the plug gage is perhaps the most easily dropped. It has too easy a tendency to roll or fall off of bench or machine. To a somewhat greater degree than either micrometers or snap gages, the measuring surfaces and square edges on plug gages are unprotected, naked, if you will; consequently, plug gages must be handled, set down, and stored away more carefully.

Limitations of Plug Gages

Experienced mechanics claim they can detect out-of-round, tapered and bell-mouthed holes readily with plug gages. The conditions being described are illustrated in the diagrams of Fig. 11. If the gage can be wiggled around in the hole, there is always a question of whether the hole is actually tapered, out-of-round or bell-mouthed or whether the looseness is due only to a discrepancy between the plug diameter and the hole size. If the taper or bell mouth is slight — not exaggerated as in Fig. 11 — and if plug and hole size are close to each other, there can be some doubt as to the inspector's ability to dis-

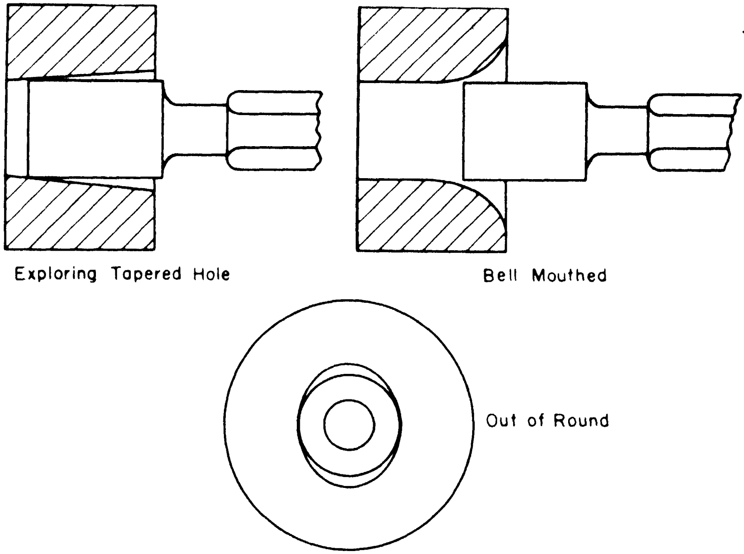


Fig. 11 Various hole conditions which may be difficult to distinguish with a plug gage.

cover the defects. Where the greatest diameter of an out-of-round hole corresponds very closely to plug size, there is considerable difficulty in diagnosing a condition of ovality.

When a plug gage is small enough to be in the "wire size" range, care must be used, of course, not to snap it off and, particularly, to make sure that the relatively long wire plug does not become imperceptibly bent.

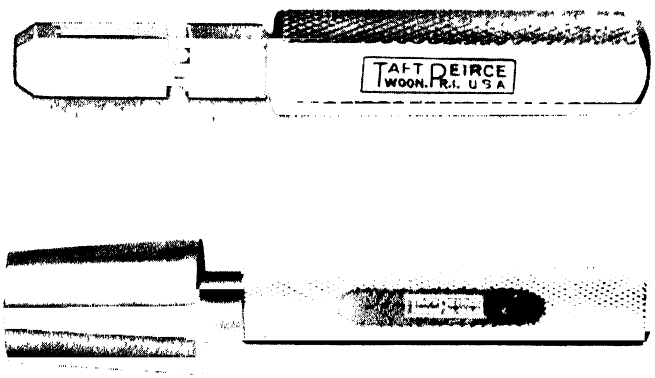
Mention of wire-size plug gages brings up another fairly common practice used especially in connection with the smaller diameter plug gages. The butt end of the plug becomes worn down in diameter (bevelled or tapered) more rapidly than the main body of the plug because, almost inevitably, the end of the plug must fiddle around a little at the entrance of the hole. If the hole edges are burred, the butt end of the plug wears rapidly, shaving off such burrs. (Which, of course, is one big reason for the design and use of pilot features on plug gage members.) Hence it is customary in many plants to regain the accuracy of plugs by grinding off or back 1/32, 1/16 or 1/8 inch from the end of the plug. This idea is followed even farther by having the inspector use only about the first 1/8 inch of the total length of the plug as a gaging, measuring or setting area. By so doing, the rest of the diameter of

the plug is not worn down, theoretically, and grinding off the 1/8-inch worn tip regains full accuracy of the plug.

Of the non-indicating and conventional and especially of the fixed type of gages, ring and plug gages come the nearest to being usable consistently to discriminations or accuracies of .0001 to .0002 inch. This statement must be limited of course to plug and ring gages made to sizes in tenths of a thousandth, as, for instance, a "Go" size of .3855 inch and a "Not Go" size of .3857 inch on a plug gage.

Special Shapes — Spline Gages — Feeler Gages

The principle of plug gages is not confined to cylindrical plugs. Figure 12 illustrates a so-called flat plug gage with "Go" and "Not Go" members designed to check the widths of slots, channels and rabbets.



Courtesy of Taft Peirce Mfg Co

Fig. 12. (Upper) Flat plug gage designed to check slots and channels. (Lower) Plug gage used to check a tapered hole.

One of the traditional methods for checking tapered holes is with taper plug gages of the sort also illustrated in Fig. 12. Usually, taper plugs show a pair of marks etched at the proper precalibrated location, as the sketch in Fig. 13 indicates. The tapered hole is too large if both marks on the gage sink down out of sight or too small if both marks are visible — the tapered hole being considered correct as to diameter and depth if the edge of the tapered hole conceals only the lower gage mark.

Following also the mating part conception, and as an illustration of the many special shapes commercial plug gages may take, a spline gage is shown in Fig. 14. Gages of this general nature check a number of conditions simultaneously.

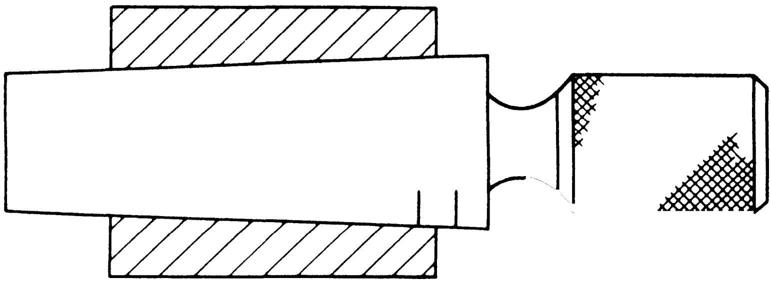
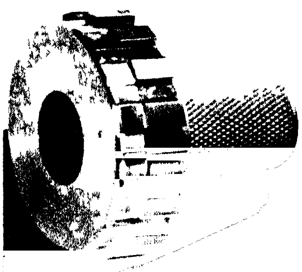
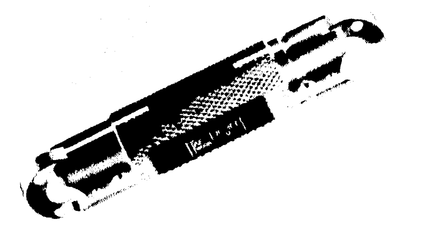


Fig. 13. Method of checking a tapered hole with a plug gage. If first gage mark enters hole but second does not, taper is correct.

A spline gage, for example, may not enter the workpiece (or fit it too loosely) not only because of workpiece diameter variations but also because segments of the splined workpiece are not evenly or properly spaced or because the splining is not parallel to the axis of the workpiece.

The keyway gage, Fig. 15, belongs essentially in the class of flat plug gages. In addition to confirming the width of a keyway, however, it checks the depth and location.



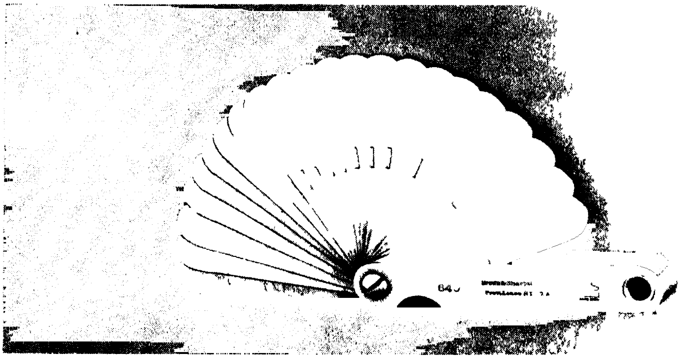


Courtesy of Taft Peirce Mfg Co

Fig. 14. (Left) Special plug gage for checking splines. Fig. 15. (Right) Double-ended plug gage for checking the width of keyways.

A close relative in the plug gage family is the thickness or feeler gage, so termed, of the general type illustrated in Fig. 16. For many of us, probably, the first time we saw a mechanic

use a feeler gage was when we watched him establish the spark gap between the distributor points of an automobile. Feeler gage sets can be secured containing a fan of blades or leaves differing one from the other by one thousandth or several thousandths in thickness as Fig. 16 shows. The desired gaging thickness can be secured by folding together the selection of leaves that will build up to a thickness, width, height or clearance dimension that is to be checked.



Courtesy of Brown & Sharpe Mfg. Co.

Fig. 16. Typical feeler gage set which has blades of various thicknesses

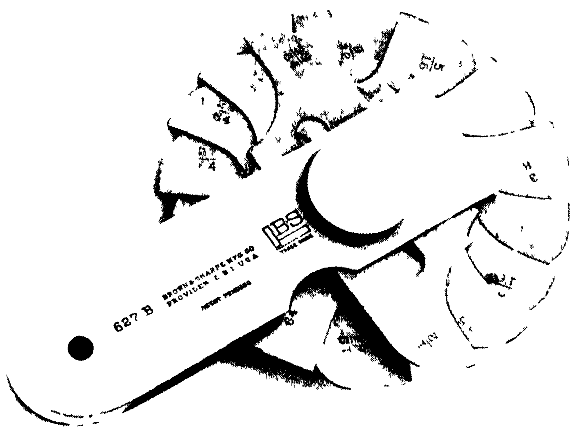
One or two precautions in connection with using feeler gages should be observed. If width or height or space must be measured to a discrimination of less than about .002 inch, it would be wiser to try to secure a standard flat plug gage, see Fig. 12, or attempt a measuring setup where a dial indicator can be used. The leaves of feeler gages become rather readily burred, bent or warped, or constant use shaves off a few ten-thousandths of thickness. The leaves of a thickness gage should be checked regularly and damaged blades replaced.

Radius and Template Gages

Most all parts and products are designed with rounded edges and with corners filled in. Appearance is not necessarily the main reason. Square sharp edges have a certain beauty too. But they become readily nicked and broken. The designer who deliberately introduces a fillet or rounded contour into what might have seemed more naturally or more ideally a sharp square corner between two sections of a shaft probably knows his business. Such a piece of metal — be it cylindrical

or square — will often stand many times the torsion, tensile or breaking strain and, if its outer edges are rounded, will take a lot of rough handling without getting nicked or burred. Another practical angle, in connection with fillets especially, is the common fact that the sharp corners or edges of cutting tools and wheels wear off readily; the mechanic has difficulty maintaining sharp corners when machining a series of pieces.

So, the industrial inspector meets radii and fillets continually in his work. Usually a radius is not a precise affair; it may make little difference to the workings of a product whether a radius is 1/16 or 1/8 inch. However, there must be some specification limit for the amount of radius or fillet the machinist should cut and the inspector checks the evidence of control with radius gages. In occasional instances, the radius must be closely controlled because of clearance conditions and the like under which the piece is to be assembled.



Courtesy of Brown & Sharpe Mfg. Co.

Fig. 17. Radius-gage set for checking both internal and external radii.

Commercial radius gage sets consist of a series of thin steel leaves, such as are shown in Fig. 17, which are used as templates after the general fashion shown in Fig. 18. The radius gage, or most any template for that matter, corresponds in one way to the steel rule — don't expect to come closer than 1/64 inch (.015 inch) with your measurement. Using a radius

gage without proper light is nearly useless. If possible, hold gage and workpiece between the light and the eye, but, if this is impossible, at all odds be sure that good strong light shines down on the junction of the radius gage with the radius or fillet being compared. Remember too, always, that the edges of radius gages can become readily nicked, burred, curled up or worn back.

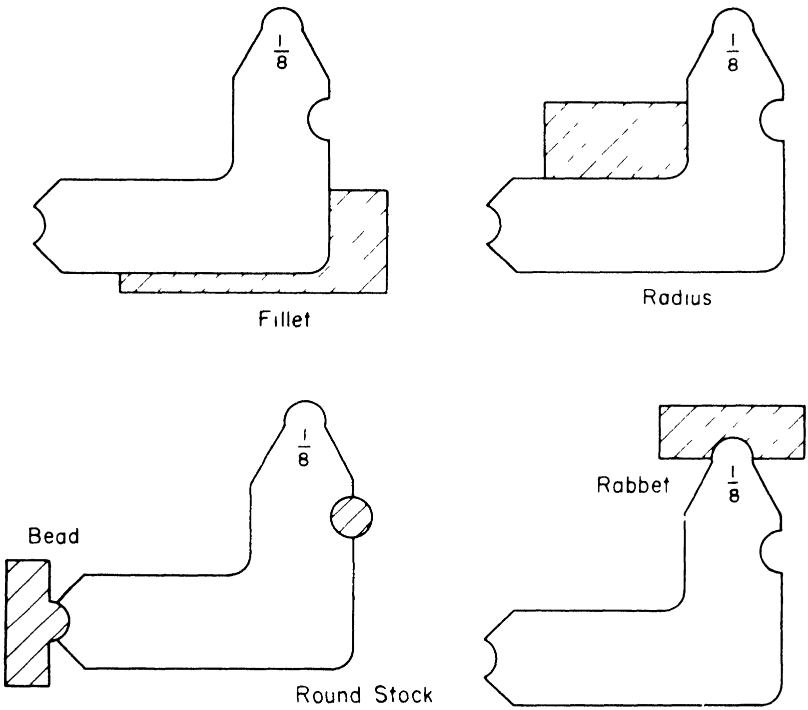
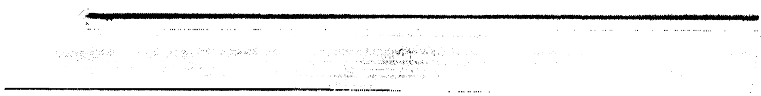


Fig. 18. Use of a radius gage to check various radii found on work-pieces.

Template gages are not confined to the small sizes indicated in Fig. 17. Inspectors in aircraft work are familiar with the man-size sheets of metal with carefully calculated curvatures profiled in them to check the contours of wing surfaces, etc., or the more exacting templates used to shape, grind, balance and polish propellor surfaces.

One of the common inspection tools, a straight edge, Fig. 19, is really a template. Likewise, the hardened steel square. The use of such tools seems evident, just from the photographs

of them, but they also illustrate another principle of mechanical inspection work that is worth enlarging upon again. Assuming that either a straight edge or a try square has been checked and found straight, true and unwarped, with edges free from nicks, burrs or worn spots, there are still limitations in their ability to measure and compare. With them, straightness or squareness can be determined to an accuracy of about 1/64 inch (.015 inch), ordinarily. If the product specifications call for greater accuracy of measurement and control in



Courtesy of Brown & Sharpe Mfg. Co.

Fig. 19. Precision straight edge.

manufacturing, the inspector would be wise to seek other means of measuring or comparing the squareness or straightness. This is the point to be emphasized. Know and admit the limitations of each type of measuring equipment and seek apparatus with finer discrimination where necessary. In other words, don't guess. And don't let everyday laziness fool you into believing you are measuring correctly, establishing the degree of conformance, simply because you don't want to bother to secure better equipment.

Checking straightness or squareness with straight edge and square involves sighting between the instrument blade and the workpiece. Hence it is preferable to hold the work up to a light or arrange in some manner to have light behind it. While light can be distinguished through a gap .00005 inch wide between two perfectly smooth surfaces, it is still advisable for the inspector to assume that he is not guessing the degree of waviness, warp or out-of-squareness closer than .010 inch. Even though you see light between a straight blade and the workpiece surface, you can never be sure of the difference between, say, .00005 inch and .0001 inch or between .001 inch and .005 inch. Few of us are gifted with such a basic sense of space.

Practical mechanics, however, do aid the sense of sight by inserting slips of paper in the gaps (ordinary typewriter or memorandum paper is .003 to .004 inch thick) or by using feeler gages where it is necessary to know fairly closely, for instance, how much more needs to be taken off the high spots of a workpiece in order to make it truly straight or square. This technique is illustrated in Fig. 20.

Fig. 20. Proper method of checking the squareness of a work-piece by using a square and a paper or metal feeler gage.

Flush Pin Gages

Flush pin gages are practically always single-purpose gages designed for the control of a particular dimension on a particular component. Consequently, they are used mostly for gaging work produced in continuing operations, mass production, or where batches of the same sort of part are made every so often. Since they are made in so many different and special styles, no attempt will be made here to go into the subject of flush pin gages other than to describe the general principle and use of them.

Suppose we consider the shape of a flush pin gage outlined in the sketch of Fig. 21, a gage designed to check diameters. As can be seen, the gage follows the standard snap gage pattern of a steel C-frame. and a reference point or anvil, *a* in Fig. 21.

Rather than fixed (or slightly adjustable) "Go" — "Not Go" upper anvils, however, the flush pin gage is provided with a hardened plunger or "pin," *p*, which, made to a snug fit in

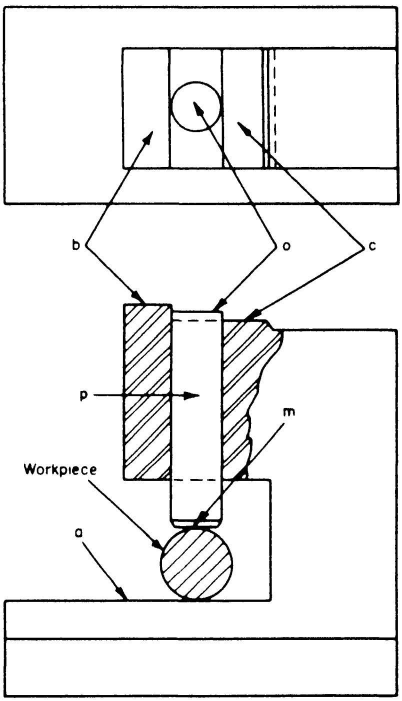


Fig. 21. Flush-pin gage of typical design.

the hole in the C-frame, will slide up and down. The measuring surface, *m*, is carefully machined square to the axis of the pin and parallel to the reference anvil surface, *a*; it is also made flat to a few millionths. At the same time the opposite end of the plunger, *o* in Fig. 21, is likewise machined carefully smooth, flat, and square to the plunger axis.

The "Go" — "Not Go" step idea is provided on this type of gage by two steps carefully planed on the upper surface of the

C-frame as at *b* and *c* in Fig. 21. The difference in the heights of these two steps — usually anywhere from .002 to .010 inch — corresponds to the tolerance or specification limits. If the gage, for example, were to be used on diameters calling for .625 ± .002 inch, the upper step, *b*, would be marked .627″ and the lower step, *c*, would be stamped .623″.

The use of the gage is indicated by the sketch in Fig. 21. The workpiece is placed on the reference anvil *a* and the pin, *p*, is pushed down on to it with standard gaging pressure. If the flat top of the pin, *p* — its upper surface *o* — protrudes above surface *b*, the work is oversize. If it sinks below step *c*, the piece is undersize. In-specification work will position surface *o* somewhere between the two steps.

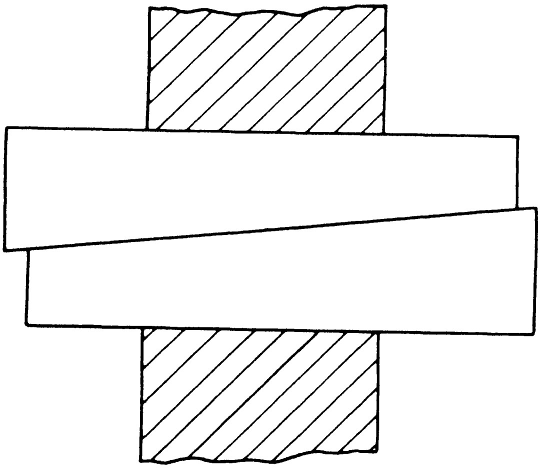


Fig. 22. Illustration showing how tapered parallels may be used to measure inside diameters.

Where the workpiece is very close to the high or low tolerance the amount the pin protrudes above either step, or sinks below, may not be discernible to the eye. The inspector then scratches across surfaces *b*, *o*, and *c* with his finger nail. The finger nail test cannot be depended on to a discrimination finer than .002 inch. If the blue print calls for a tolerance spread less than .002 inch or if the difference between steps *b* and *c* is less than .002 inch, the accurate use of the gage should be seriously questioned and other means of measurement (micrometer, vernier or indicator equipment) should be employed.

Tapered Parallels

Tapered parallels offer another means for measuring an internal diameter. The proper pair of parallels is selected and slipped into the hole with their flat tapering surfaces facing each other and their rounded parallel surfaces in position for contact with the inside surface of the hole. By sliding one tapered surface against the other, a wedging effect is obtained which brings the outside rounded surface of each block into contact with the hole surface as shown in Fig. 22. It should be mentioned that in obtaining this wedging contact only the standard gaging pressure of one or two pounds should be used.

Courtesy of Brown & Sharpe Mfg Co

Fig. 23 Using a micrometer to measure the setting of the tapered parallels after they have been wedged in place as shown in Fig. 22.

The outside contact surfaces of the two blocks are rounded to some curvature *less* than that of the hole to permit contact of both on the hole diameter but care must be used to make sure they are properly centered. It is possible to lock them to one side a few thousandths of an inch and thus measure a chord and not the true diameter. The internal diameter measurement is then made with a micrometer as shown in Fig. 23.

While the measurement of an internal diameter is illustrated, tapered parallels are also used to check the width and parallelism of slots and to "plug" holes for measuring hole center distances and layout.

Tapered parallels should be carefully examined at each use for edge nicks and burrs and worn, rough or corroded spots; in other words they must be used carefully and kept always in good shape — oiled or rust proofed before they are put away. They must, of course, be carefully cleaned to remove the rust proofing, dirt, and grit at each use. Again, there is a question as to the ability of tapered parallels, with micrometers, to measure to a precision finer than .0005 inch. Tapered parallels, of course, cannot be so readily used in a blind hole or where the hole is not accessible from both sides.

CHAPTER 7

Surface Plate Methods and Equipment

Essentially, up to this point, several fundamental methods of measuring have been discussed. The method illustrated by the steel rule — a length graduated or subdivided which, held up against an object, allows some pertinent dimension of that object to be determined by comparing by eye the dimension with the count of graduations on the measuring length or rule.

The sense of touch, aiding vision, has been brought in by suggesting the use of calipers to span a dimension and then comparing the caliper spread with a set of graduations, as on a steel rule.

Combining mechanical pressure and the sense of touch with a much finer discrimination in determining actual dimensions, the vernier principle was applied to the graduated length, such as the steel rule, with the equivalent of calipers attached to it.

Another addition to the methods of calipers, graduated lengths and vernier devices was illustrated by the micrometer with its added basic principle of a screw thread which, when turned, advanced or withdrew caliper jaws 1/40th of an inch per turn.

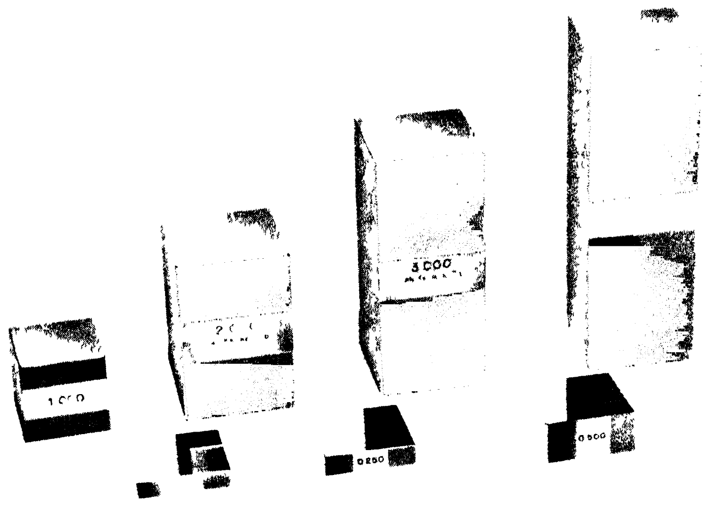
The principle of the mating part plus the principle of a fixed measuring unit for comparison has been brought out in the discussion of fixed gages, such as snap and plug gages.

Precision Gage Blocks

The invention of gage blocks has resulted in another basic method being used in the field of precise measurement. If you were building a brick wall or column with bricks three inches thick, using one-half inch thick layers of mortar between the bricks, your wall, 7 bricks high, would measure 24 inches over all because 7 three-inch bricks stacked on each other equal 21 inches and the 6 mortar joints, each one-half inch thick, add

3 inches more. Or, if you took twelve 1-inch kindergarten blocks and erected a tower for a child with them, the tower would be 12 inches high, more or less, depending upon the uniformity of the blocks and the flatness and smoothness of their contacting surfaces.

Commercial gage blocks are special steel blocks, hardened, with carefully machined parallel and flat surfaces. They are used to build up various gaging lengths essentially as suggested in the simple brick and play block examples above.



Courtesy of The Van Keuren Co

Fig. 1. Gage blocks of various sizes.

Commercially, too, gage blocks have been standardized so that in a cross section perpendicular to their length axes they usually are either a 1-inch square or a rectangle that is 3/8 x 1-3/16 inches. (One maker of gage blocks furnishes discs like coins or, in longer lengths, like rods.) While in the shop, terms like "Jo" blocks or "Hoke" blocks or just plain "blocks" have come into common use, the technical name for any individual gaging block is a *gage*. (The manufacturer of the round, coin- or rod-like gages, for instance, calls them as a trade name, "microgages.")

Gage Blocks Are Used for Linear Measurement

Figure 1 shows several sizes of these gages, and illustrates the concept of a gage block which the new inspector should fix in his mind. The length of the gage or gage block is its fundamental feature. By joining a 1-inch block to a 2-inch block, 3 inches in length is obtained. To assure the fidelity of the lengths of gage blocks the manufacturer makes sure, above all, that two of the surfaces or planes are strictly parallel to each other, truly perpendicular to the length axis, and that these parallel surfaces are as perfectly flat as he can make them. Commercially, the flat parallel measuring surfaces are made square to the other or "side" surfaces of the blocks.

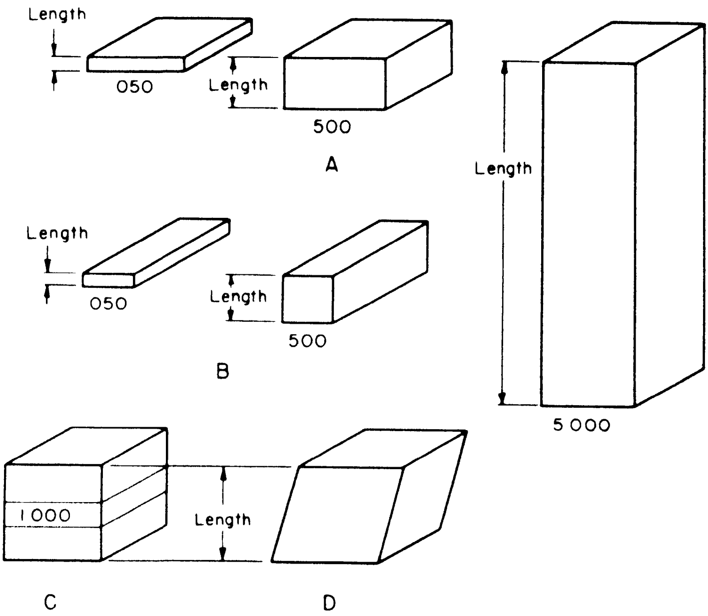


Fig. 2. (A through D) The "length" of the gage blocks is the distance between measuring surfaces.

Commercially also, the gage block manufacturer usually makes the contrast between the highly polished, flat and parallel measuring "ends" of the blocks and the "sides" more evident by putting a duller (sand blast) finish on the sides or at least by stamping the gage size on one of the sides.

Figure 2 illustrates these points; the "length" of the gage block, whether it is cut from .050-inch thick metal or .500-inch

or 5.000-inch, is the dimension between the polished, flat and parallel measuring ends as shown. In the case of the .300-inch long block of the rectangular type — series B in Fig. 2 — it might be difficult to distinguish which are the two "ends" because the block's other thickness dimension is 3/8 inch (.375 inch). Or, in the case of the one-inch square type of block, since the 1.000-inch gage is, of course, practically a cube, unless the ends were distinguished by their high polish or, better, unless the non-measuring sides had a contrasting finish, pattern or size marking as illustrated at C in Fig. 2, the precise measuring "length" or axis of the block might not be readily distinguishable.

While the manufacturers use care to put out "square" blocks, as a matter of good workmanship and for convenience in use, they do not guarantee this squareness. Some slight degree of condition D, Fig. 2, may exist. In other words, gage blocks should not be used to check squareness. The manufacturers do guarantee however a certain flatness of the measuring ends as well as their parallelism to each other and particularly the length between the ends.

There are several reasons for going into all this detail. One of the first rules a worker should adopt when using gage blocks is never to pick them up or grasp them by the ends. Take hold of them, handle them, by their sides. In the same vein, as far as possible set gage blocks down on the work bench resting on their sides. The ends are the precision surfaces and handling will damage them.

Gage blocks normally emerge from their manufacturing process with end surfaces that are flat, true planes within two millionths of an inch level. The two end planes are usually parallel to each other also within two millionths of an inch. The length of a gage block is usually guaranteed to be within about two, five or ten millionths of an inch of the size stamped on it, depending on the commercial grade and price of the block.

As a matter of space or of length, a millionth of an inch is not much. It is about as hard to comprehend mentally as the astronomical light-year or the billions of dollars in recent federal government appropriations. Hence, gage blocks are not to be mishandled. (Actually they do withstand a great deal of unwarranted abuse without appreciably affecting the desired results in precision measurement.)

Grades of Gage Blocks

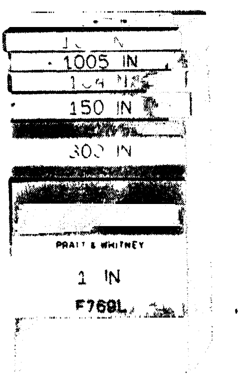
Commercial gage blocks are supplied as "master" blocks, "inspection" blocks, and "working" blocks; master blocks having almost invariably .000002-inch accuracy in specified length, inspection sets around .000005-inch accuracy, while working sets are liable to show errors in length up to 10 millionths or .000010 inch. The usual, and best, practice is to use master blocks very seldom and never directly on work or shop measurements. They are kept solely to compare with or to calibrate inspecting and working blocks. To a somewhat similar degree, the use of the inspection grade is limited as much as possible. An attempt is made to maintain their accuracy, precision and serviceability in order that they may be used confidently to settle, perhaps, some dispute over the exact dimensions on workpieces, the precise setting of a comparator or the accuracy of, say, micrometers or other gaging equipment.

It might be well right here to digress enough to emphasize that gage blocks, so far as the shop is concerned, are basic measuring equipment. In the standards laboratory it may be possible by optical means and spectroscopy, by means of light waves and interference bands, or by means of electronics, to be as basic and fundamental as the development of the science of measurement permits. Such delicate apparatus and techniques cannot be used of course in the shop. Fortunately, commercial gage blocks are so sturdy, reliable and dependable, that it is possible to obtain with them basic accuracies and discriminations in the shop that compare very favorably with what the laboratory can do.

Stacking Gage Blocks for Measurement

To get a particular linear dimension, then, with gage blocks, they are built up, one on the other, using a suitable selection of various size blocks, until a "stack" like that shown in Fig. 3 is obtained. The gage block manufacturer uses of necessity, as has been stated, a tolerance of a few millionths in trying to obtain the precise length of each block he makes, at the same time trying to maintain parallelism and flatness. Some of these tolerances or gage allowances may fall a few millionths on the plus side; while as many others, it has been found, may cause the actual gage length to be minus. Gage blocks wear down to the minus side from use, of course, and certain size gage blocks usually wear faster than others because they happen to be

used more. So, in practice, it is found that where several gage blocks are stacked together the pluses and minuses, to use an expression, usually add up algebraically and the resulting or total length may show less error in millionths, either plus or minus, than the known error in any one of the individual blocks.



Courtesy of Colt Industries, Pratt & Whitney Machine Tool Div

Fig. 3 Gage blocks stacked to obtain an over-all dimension of 1.7545 inches.

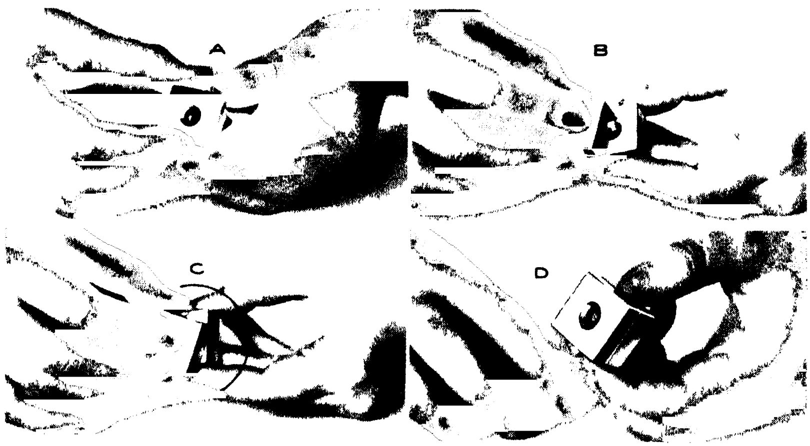
Unlike a child's building blocks, however, gage blocks are not simply rested one on the other. More like the bricks in a wall, they are actually cemented together. To use a shop term, they are "wrung" together. They are pressed together with a twisting motion that not only squeezes out the air between the almost geometrically flat surfaces of the gage block ends but gains additional adhesion from the phenomenon usually explained as a combination of molecular attraction and the "cementing action" of oil film or moisture on the adhering surfaces. Hence there is no error in the total length of a stack of gage blocks due to any measurable spaces between the blocks' end surfaces.

Perfectly dry blocks will not stick together as, for instance, when blocks are carefully cleaned free from dust, grit, oil or grease by bathing them in pure grain alcohol and then letting them dry completely moisture-free from any water absorbed in the alcohol by evaporation in air. To put gage blocks together, then, for shop inspection and gaging purposes the surfaces are cleaned free from grit and foreign matter but they are not cleaned in the sense of removing a final, impalpable oil film on the ends or wringing surfaces.

Wringing Gage Blocks Together

The steps in wringing blocks are shown in Fig. 4-A, -B, -C and -D. These steps should always be taken exactly in the

order shown — no step should be carelessly slighted. The two blocks, properly cleaned, are brought together flat as shown in Fig. 4-A and oscillated slightly with very light pressure. Be sure, in this step, that one block is not slightly tilted. If so, its edge may tend to shave, wear, or roughen the precisely flat, polished end surface of the mating block. This technique also minimizes the danger of one block scratching the other, and it will detect any foreign particles between the surfaces if the finger pressure is light but firm. Shift the blocks to the position of B in Fig. 4. If the blocks are clean, untilted — flat to



Courtesy of Colt Industries Pratt & Whitney Machine Tool Div.

Fig. 4 (A through D) Four steps in wringing two gage blocks together.

each other — they will begin to take hold. (If any grit between the blocks has been felt, stop right there, of course, and clean them again.)

With the top block half out of engagement, the two are slid together, using standard gaging pressures and a rotary or spiral motion about as Fig. 4-C indicates. Maintain the motion until the blocks are professionally lined up as in Fig. 4-D.

A very common tendency in wringing blocks is to use unnecessary pressure to wring them together. Brute force is not needed to secure proper wringing or adhesion. And too much pressure not only makes it harder to separate the blocks but also sets up unnecessary wear. Furthermore, nothing is contributed to the accuracy of the setup. While it is possible to wring gage blocks together with an adhesion that will support

several hundred pounds, all the inspector is after is just enough wringing pressure and just enough adhesion so that the blocks cannot inconveniently fall apart when they are moved or used.

Gage Block Measuring Technique

The proper manner of setting up a gage block stack to a given dimension can be considered as a series of steps.

First, place the box of gage blocks handy for the measuring job to be done by them. The business of walking back and forth fetching first one gage block and then another is not only inefficient, but there is also the constant danger of dropping a gage. Handling several blocks at a time in your hand only tends to rattle them together and nick or scratch them. Handling also starts up corrosion of blocks. Sweat, which is always present on the hands, contains acid elements. If the hands are dirty or oily from other work, a trifle of corrosive acid or alkali element may be resident, picked up from handling workpieces where acid or alkali was present. Quite a percentage of workers, male and female, unfortunately have an excessive acid condition which is reflected in their sweat glands. They are usually, like Typhoid Mary, unaware of it. But let them so much as touch an unprotected precision measuring surface and a rust spot will soon appear. Clean and rust proof gage blocks as soon as possible after anyone has used them. If the gage blocks have been properly cleaned, oiled or treated with a rust preventive when they are put away, casual handling will unlikely set up corrosion. However, the danger is everlastingly potential and the longer gage blocks are in contact with human skin, the greater the danger.*

Gage Blocks Must be Kept Clean

The second step should inevitably be that of putting down a clean sheet of paper, a clean cloth or chamois between the gage

* Several makes of gage blocks are chrome plated. Chrome plating obviates the danger of corrosion, of course. Chrome, being a so-called slippery metal, also seems to withstand better the frictional wear of wringing. Where chrome plated blocks finally wear minus they can be "built up" by replating and then be sized and lapped. But it is nearly impossible to get chrome plated blocks to stay wrung together. For this reason they are disliked by experienced workers and the accuracy of stacks of chrome plated blocks is also suspected. Add to all this, the tendency of chrome plating to flake off, especially at the edges.

block box and the work. The idea is to have a clean location prepared on which to set the gage blocks after they are selected from the box. Never, as has been said, handle gage blocks by their precision lapped ends, if it can be avoided. Take hold of their sides and set them down on their sides. Never put gage blocks down on a bare bench top or machine bed. Set them on the clean paper, cloth or chamois prepared for them.

As a general thing a clean paper towel or a clean piece of typewriter paper is used. (Never a newspaper; it is probably dirty.) Some mechanics prefer the softer facial tissues but tissue, like cloth, felt or velvet, bothers sometimes, because it sheds lint or fuzz which may actually interfere with the accuracy of a precise measurement. Perhaps the best material is chamois. Chamois is soft and fuzzless. If a gage block is accidentally fumbled and dropped, the chamois cushions the fall. The one danger in the use of chamois (also cloth) is that it readily collects dust and grit and most of us, being lazy and inattentive, fail to wash it out thoroughly just about every time we use it. By and large the best solution seems to be to line the bench top area near the gage block box with a clean piece of cloth or felt as a soft mat and top the cloth with a clean piece of paper such as a fresh paper towel.

(It should be unnecessary to suggest at this point that perhaps the inspector needs to interrupt his routine to wash his own hands, especially if he has been recently handling extra dirty components or parts. In general — sloppy work place, sloppy worker, sloppy work.)

Selecting the Proper Blocks

The third step is the selection of the proper blocks for the particular measurement needed. Before proceeding, it might be wise to re-examine the blue print or specification tolerances and review the nature of the work, the measurement of which seems to involve the use of gage blocks. If the workpiece tolerances are less than .001 inch, if it is felt that the decision or setup to be reached depends on extra precise measurement, then gage blocks can be the proper tools. But if the limits are broader, the work and the measurement less particular, some alternative measuring method or medium probably should be chosen. The point is that too many times an inspector is prone to get out gage blocks when micrometers or vernier equipment

would be easier and faster to use and adequate as to accuracy or discrimination. Use gage blocks as little as possible. They are perishable and expensive. It costs time and money to keep on constantly rechecking them for wear and inaccuracy. As a rule of thumb, it has been said that gage blocks wear down a full millionth of an inch, even with very careful use, in the vicinity of 200 wringings. Use other measuring techniques and apparatus if possible.

Let us suppose, however, that the set-up calls for a gage block stack for 2.6437 inches.

Examine the box or set of gage blocks available. A popular size box contains 81 blocks, see Fig. 5. Another size is the 36-piece set. Gage makers' catalogues list other assortments and sets including blocks in metric measurement. The inventory of block lengths in an 81 piece set is listed in Table 1.

Table 1. Sizes of Gage Blocks in 81-Block Set

First: One Ten-Thousandth Series — 9 Blocks

.1001″	.1002″	.1003″	.1004″	.1005″.	1006″	.1007″	.1008″	.1009″

Second: One Thousandth Series — 49 Blocks

.101″	.102″	.103″	.104″	.105″	.106″	.107″	.108″	.109″	.110″
.111″	.112″	.113″	.114″	.115″	.116″	.117″	.118″	.119″	.120″
.121″	.122″	.123″	.124″	.125″	.126″	.127″	.128″	.129″	.130″
.131″	.132″	.133″	.134″	.135″	.136″	.137″	.138″	.139″	.140″
.141″	.142″	.143″	.144″	.145″	.146″	.147″	.148″	.149″	

Third: Fifty Thousandth Series — 19 Blocks

.050″	.100″	.150″	.200″	.250″	.300″	.350″	.400″	.450″	.500″
.550″	.600″	.650″	.700″	.750″	.800″	.850″	.900″	.950″	

Fourth: Inch Series — 4 Blocks

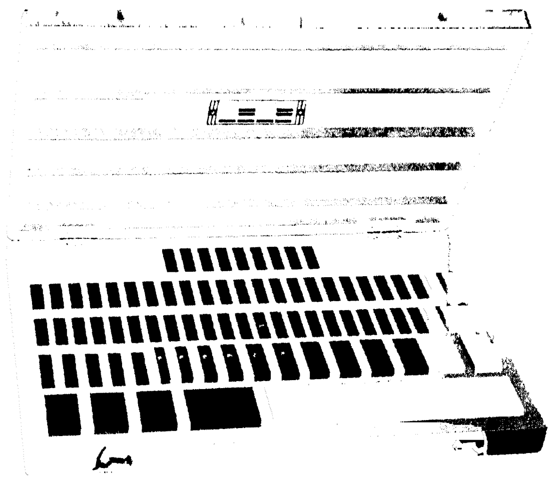
1.000″	2.000″	3.000″	4.000″

The trick in selecting blocks from the box is to eliminate the right hand figure or digit of the specification. In this example the dimension is 2.6437 inches. To eliminate the final digit 7, select the .1007-inch block from the box. Using a piece of scratch paper and a pencil, subtract .1007 from 2.6437, getting 2.543, as below.

$$\begin{array}{r} 2.6437 \\ -.1007 \\ \hline 2.543 \end{array}$$

(This procedure of selecting a block to eliminate the right-hand digit is followed in each succeeding step.)

Now the digit 3 is the right hand digit and the selection of the .103-inch block, see Table 1, will eliminate it as the next step, below.



Courtesy of Brown & Sharpe Mfg Co

Fig. 5. A set of gage blocks consisting of 81 different sizes.

$$\begin{array}{r} 2.6437 \\ -.1007 \\ \hline 2.543 \\ -.103 \\ \hline 2.440 \end{array}$$

Again, the digit 4 is the essential right hand figure and the .140-inch block is the next choice.

$$\begin{array}{r} 2.6437 \\ -.1007 \\ \\ 2.543 \\ -.103 \\ \hline 2.440 \\ -.140 \\ \hline 2.300 \end{array}$$

Rather obviously, now, the next choice is the .300-inch block and, finally, the 2.000-inch block.

The selected blocks should now be resting on the paper covered mat ready for work. But first read the sizes from the selected blocks themselves and list them down on the scratch pad. Add the list up to check the correspondence of the total to the original specification size.

.1007
.103
.140
.300
2.000
2.6437

Always perform this last mentioned "rite." Many times, unwittingly, the wrong size block has been picked out of the set; occasionally a mistake has been made in the paper-and-pencil operation of selection by elimination of digits. This final check is a safeguard against such errors.

Several Combinations are Usually Possible

As an inspector gets used to selecting blocks, he will find other combinations designed to allow the use of a minimum number of blocks. In the example above, for instance, the .103-inch, the .140-inch and the .300-inch blocks were selected. But the gage block set contains a .143-inch block and a .400-inch block. The use of the .103-inch block was not strictly necessary. The professional trick is to use as few blocks as possible to build up the total stack.

On the other hand, some measuring problems call for the simultaneous use of two equal stacks of blocks or for the use of two stacks the building up of which might call for the same size block in each stack at the same time. (The use of the sine bar, described in a section farther on, very frequently brings up this contingency.)

The example offered directly below points out the use in Stack A of the .143-inch block in place of the .140-inch and .103-inch blocks just mentioned above, and also the use of combinations of substitutions in Stack B for blocks already in use. The specifications in this example called for the 2.6437-inch stack and another simultaneous stack for 1.6437 inches is also to be made up.

2.6437	
—.1007	.1007
2.5430	
—.143	.143
2.400	
—.400	.400
2.000	2.000
	2.6437

Stack A—4 blocks

1.6437	
—.1003	.1003
1.5434	
—.1004	.1004
1.4430	
—.103	.103
1.340	
—.140	.140
1.200	
—.200	.200
1.000	1.000
	1.6437

Stack B—6 blocks

As can be seen, in order to build the 1.6437-inch stack, B, the first substitution came up in the combination of the .1003-inch plus .1004-inch blocks in place of the single .1007-inch block already in use in stack A, and the second substitution involved .103-inch plus .140-inch blocks instead of the already used .143-inch block. In other words, the 1.6437-inch stack B used two more blocks than the 2.6437-inch stack A.

Cleaning the Gage Blocks

The fourth step in the use of gage blocks is to clean them ready for wringing and stacking. The cleaning tools are a soft clean cloth, chamois or tissue, and cleaning solution such as carbon tetrachloride or Stodsol, plus clean hands and the clean paper topped bench location to set the cleaned blocks on. (Benzene and gasoline are not taboo as cleaning fluids if the fire and explosion hazard are properly recognized. Some favor the use of kerosene. It is wise to filter kerosene clean first through a chamois, however.)

Checking the Gage Blocks for Injury

Connected with the cleaning step in the use of gage blocks are several items of surveillance. Note from the appearance of the blocks whether or not the blocks were properly cleaned and oiled or rust proofed the last time they were used. If blocks in poor shape in this respect are discovered, a bit of detective work directed toward correcting somebody's care-

less habits should be performed. As each block is cleaned, examine the polished ends for scratches, worn spots and corrosion. Check the edges with your eyes and finger nail (perhaps even with a magnifying glass) for nicks. *Don't* use scratched, nicked, dirty or rusted blocks.

Where gage blocks which have apparently been properly cleaned and rust proofed reveal rust and corrosion spots, more detective work should be in the offing. Look for (a) an employee (it might be yourself) whose sweat pores exude the type of acid which will start up a corroded spot simply from touching a block or, (b), look for oil, grease or rust proofing compounds that contain excess acid or alkali,* or, (c), check to be sure the blocks were properly cleaned free from corrosion at the last using.

Scratches and nicks have been mentioned. At first thought, it seems as if a slight scratch on the polished measuring surface of a gage block should be harmless, but if a scratch on metal is examined under a powerful glass it will be seen that the metal has not only been dug out, leaving a depression, but that the metal has also been forced into minute ridges projecting above the rim of the scratch. A scratch looks like a furrow in a plowed field. The plow not only scrapes out a V trench but it also piles dirt up on either side. A scratched block can scratch another block.

Nicks and digs along the edges do the same thing. It is very easy to drop a gage block or unconsciously rap it against a bench or piece of metal and never realize that a tiny nick has been raised on an edge. While the edges of commercial gage blocks are deliberately "broken" a trifle in the sense of being slightly dulled, they are not definitely bevelled or rounded.

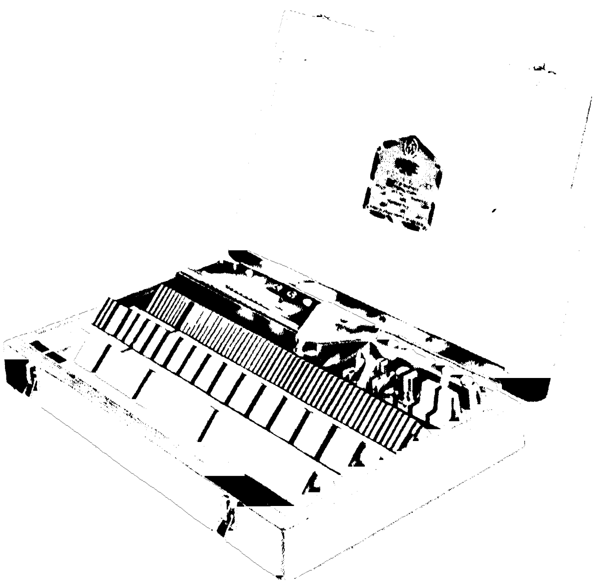
In wringing the cleaned blocks together to form the stack, following the instructions previously given and illustrated in Fig. 4, it is customary to wring them together in the order of size. Using the example of stack A, previously mentioned, for 2.6437 inches, which required 4 blocks, the .400-inch block would be first wrung on to the 2.000-inch block. Then the .143-inch block would be added to the .400-inch block and, finally, the .1007-inch block would top the stack.

* Gage block manufacturers will recommend suitably tested oils, greases or rust proofing compounds. Many industrial oil and grease suppliers catalogue suitable compounds. Or see your laboratory, engineering or purchasing departments.

At this juncture, the stack of blocks is stood end up on the clean paper, usually with the largest size block at the base of the stack and resting on the polished measuring end of this largest block. The blocks, as a unit stack, are to be handled, as always, by gripping the sides.

The Use of Wear Blocks

For the purpose of protection, particularly when the block stack is being used as a gage for direct measurement, some gage manufacturers supply so-called wear blocks. Several wear blocks come with each such set. They are usually .050-inch or .100-inch thick and they are wrung on each end of the stack being made up. (Of course, in calculating the total height of a gage-block stack, with wear blocks in use, the calculation takes into account the thickness of the wear blocks.) The idea of wear blocks is implied in the name — they are to take the wear and tear of handling, setting down and measuring with a gage block stack and it is expected that they will be checked regularly and perhaps replaced rather often. Obvious care is usually taken too, in the use of wear blocks, to face the same



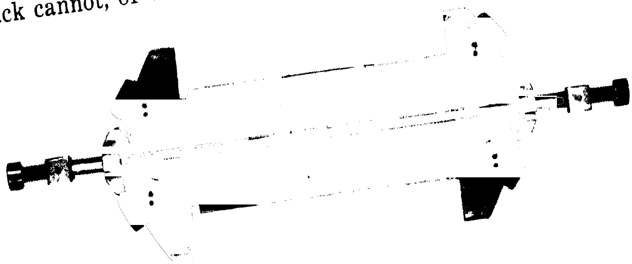
Courtesy of Colt Industries Pratt & Whitney Machine Tool Div

Fig. 6. Commercial gage blocks with countersunk holes that facilitate clamping the blocks together by means of a rod through the center.

end out, thus keeping the opposite surface always free from scratches, wear and dirt. This method preserves one face of a wear block always smooth for wringing against the regular measuring blocks.

Provisions for Clamping and Use of Attachments

The type of gage blocks illustrated in Fig. 6 come with countersunk holes which allow the blocks to be clamped together with extension rods and flat head screws, in addition to their being wrung together. By this device a gage block stack cannot, of course, fall apart in use.



Courtesy of Dearborn Gage Co

Courtesy of Colt Industries, Pratt & Whitney Machine Tool Div

Fig. 7. (Upper) Gage blocks of type shown in Fig. 5 clamped together to form a snap gage. (Lower) Gage blocks of Fig. 6 clamped together to form a snap gage.

Another purpose behind this type of block design is the provision for adding caliper and scriber point attachment blocks to the main stack so that for certain occasions the gage block stack becomes a complete fixed snap, caliper, plug or height gage in itself. Fig. 7 shows types of clamping and holding devices for both types of gage blocks illustrated in Figs. 5 and 6.

In an early section describing the steel rule, it may be recalled, the "hook" attachment or hook rule was discussed. The statement was made that "a general difficulty in connection with various helpful attachments offered with measuring equipment, to make its use easier and quicker, is the fact that the accuracy of the attachment itself is too seldom questioned. The attachment . . . becomes relied on and yet by its very nature, design and use proves to be the item that becomes bent, worn, loose and inaccurate. . . ."

Because gage blocks are basic measuring equipment, because their accuracy may be relied on down to a few millionths of an inch, the inspector should give whatever attachments he uses priority in the attention he pays to checking and calibration. He should also learn his own shop's standards and preferences as to the types of attachments to be used or, failing to get clear-cut answers on this subject, he can consult manufacturers' catalogues and instruction books.

Guarding Against Injury to Measuring Surfaces

One quite common shop practice represents a paradox. It has been said that perfectly clean, dry, grease free blocks will not wring together. It has also been said that the acids in natural sweat will start up corrosion. Yet many time inspectors and mechanics will be seen carefully degreasing and cleaning gage blocks only then to wipe the measuring ends quickly on their wrists or forearms or even against the sides of their noses. The idea, of course, is to get a film of oil on the polished gage block surface for wringing purposes. Perhaps it is assumed that the sweat oozing only from finger tips contains acid, that the oily skin of wrist, forearm, nose or scalp is singularly pure. The machining trades display a number of quaint, traditional inconsistencies like this. It is safer to give each cleaned block a dab with a clean soft rag slightly moist with a strictly neutral, pure and light mineral or vegetable oil. If the blocks have been cleaned with petroleum products, enough resident grease usually will remain for wringing purposes.

The effect of corrosion on hardened steel gage surfaces is deceptive because, unless a high powered glass is used, it is not seen, many times. The metal, as it first corrodes, frequently does not noticeably discolor. The corrosion, itself, is substantially the formation of a molecular fineness of powder

or a disintegration and crumbling of the surface to an impalpable depth, all of which, nevertheless, scrapes right off when the blocks are together.* Add this to the natural burnishing and shaving action, the mechanical wear from wringing, and the blocks may lose length an unnoticed millionth of an inch at a time.

The use of gage blocks in measuring procedures will be discussed further in connection with descriptions of other measuring apparatus and methods farther on. Two fundamental points should be taken up here, however.

Cleanliness is an Important Factor

It would be inconsistent to clean, check and handle gage blocks meticulously and then pay no attention to the condition of other gages, surface plates, machines or workpieces the gage blocks are to be used with and on. Any surface a gage block or stack is to rest against should also be as carefully cleaned free from grit, oil or corrosion. Examine the work surfaces also for scratches, nicks and burrs which will damage the polished gage block ends or attachments. As far as pressure is concerned, gage blocks or stacks should be applied delicately, though firmly. A gaging pressure not exceeding eight ounces (half a pound) should be sufficient. Never ram a gage block stack into position; the use of gage blocks is always a slow-motion operation.

Temperature Changes Can Affect Accuracy

Another factor too commonly forgotten or carelessly ignored when gage-block stacks are used is the effect of temperature. This question is to be taken up again in detail farther on, but right here it should be pointed out that a one-inch gage block will expand or lengthen about six millionths of an inch (.000006″) for every degree Fahrenheit its temperature increases. (In like manner it will shrink .000006 inch per degree drop in temperature.) A gage block's temperature can increase from normal room temperature some ten degrees in something less than ten minutes if it is simply held in the hand.

* Try not to leave gage blocks wrung together any longer than necessary and never leave them wrung over night. This same idea was mentioned during the discussion of the maintenance and care of micrometers. An electrolytic effect transpiring between two metal surfaces in close contact speeds up the chemistry of corrosion or adds a special pitting effect of its own.

To illustrate the effect of ordinary inaccuracies in measurements occurring from the everyday use of gage blocks, suppose a situation (not uncommon) where a gage block set-up (single or a stack) is made for 10 inches in length. The ordinary cleaning, wiping, wringing and handling of the blocks, plus the handling of the completed stack in the measuring or comparing operation will usually mean contact with the inspector's hands for about ten minutes, perhaps, and the block's or stack's temperature will have increased probably about 10 degrees F. Multiply the .000006-inch expansion per inch per degree by the 10-inch length and the 10-degree temperature rise and the stack will actually measure .0006 inch more than it should.

$$.000006 \times 10 \times 10 = .0006$$

To put it as a sort of rule of thumb, ordinary handling of a one-inch length of blocks might produce an expansion error of nearly .0001 inch and ordinary handling of a ten-inch gage-block stack can readily develop more than half-a-thousandth inch error.

The professional custom is to make up the gage block stack and set it on, near or against the surface plate, gage, machine or workpiece with which it is to be used for about twenty minutes. In this manner, the gage block stack temperature equalizes to or with the apparatus or work it is to be used on. Don't expect accuracy from gage-block stacks where they and the apparatus or work are in direct sunlight, near steam radiators or in line with the draft from doors, windows and fans.

The handling of gage blocks has been gone into at considerable length because most of the principles and techniques described and the warnings issued apply to the everyday use of practically all precision measuring apparatus.

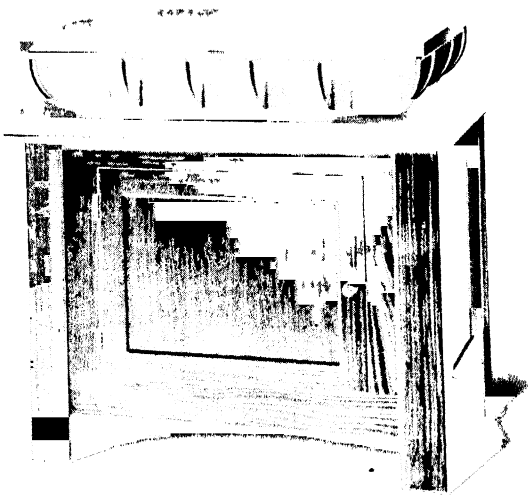
Surface Plate Provides Basic Reference Surface

In several previous sections, considerable attention has been directed to the "reference point" and to reference surfaces like anvils and jaws on gaging equipment. The surface plate, in one sense, is the epitome of the reference surface. Or, to put it another way, if the inspector, when using a surface plate, always keeps the geometrical idea that it is a reference surface in mind, he will complete and use surface plate set-ups to the greatest advantage.

A surface plate, primarily or geometrically, is a truly flat, level plane. Practically or physically it may be a cast iron, granite or glass block, set level on bench, stand or table, with its one flat, polished surface facing upward.

Types of Surface Plates

The cast iron surface plates, which are traditionally more common, have special webs and structural formations under the surface so they will be as light in weight as possible and yet will not warp or settle after the castings have aged, as shown in Fig. 8. In fact, the true plane of the surface is not



Courtesy of Taft Peirce Mfg Co

Fig. 8 Typical cast-iron surface plate

machined and "scraped" until the original casting has been out of the mold for several months — until it has really aged and all internal stresses have subsided. During the last few years true, flat, smooth surfaces have been polished on granite blocks and granite surface plates have increased in popularity. Occasionally a cast, polished glass plate is seen and ceramic surface plates are also manufactured. The iron plate has the advantage of allowing a certain amount of wringing (see farther on) and holes are not readily chipped out of its surface or edges from something dropped on it. The glass plate

will shatter, craze or break and be destroyed if heavy pieces happen to be dropped on it.

The granite (and glass) surface plates present one advantage at least over the iron plates. When a dig or scratch is accidentally made in iron there is not only the below-surface depression but metal is forced up the sides of the scratch above the true plane of the surface in the same manner as a ploughed garden furrow. When a granite surface is scratched, fine particles of granite are routed out. There is the depression of the scratch itself but no accompanying ridge because the loosened particles of granite readily brush away. A scratch on an iron surface must be suspected; it may elevate or tip, by a few ten-thousandths or thousandths of an inch, whatever apparatus is set on it. Scratched granite can be disregarded in this respect.

Manufacturers claim that the scraped surface of an iron surface plate is free from warp, waviness or chatter — that it is a true flat plane within .0001 inch between any two points on its surface. Considering the possibilities of scraping errors, or of some possible settling or warping due especially to local sunlight, drafts, vibration and temperature conditions surrounding the plate in use, and to the presence of scratches on the surface, it is probably safer to presume a possible surface error of .0002 inch or even .0005 inch. Granite surface plates are claimed to be more reliable in this respect.

On the other hand, because of the crystalline or molecular structure of the surface of the granite block any degree of wringing is practically impossible. Where wringing is perceptible, as in the case of an iron surface plate, errors of manipulation are reduced if not eliminated. Hence, because a height gage or other apparatus slides or slips along the granite block so readily, the inspector should take somewhat extra precautions to be sure the apparatus does not tip or lift. An unconscious error up to .0001 inch or .0002 inch is possible under these circumstances.

Either type of plate will wear down. A gradual hollow may form in an area commonly and regularly used, and when the plate is checked, a wear error of several ten-thousandths is often found. Plates should be checked at least every few months — their surfaces explored with a .0001-inch discrimination indicator or with an optical flat. Either type of plate can be returned to the manufacturer for reconditioning.

Care and Use of Surface Plates

Reference to manufacturers' catalogues will show that surface plates can be obtained in many sizes, from 4×4 inches area to 48×144 inches. As a consequence, in many inspection areas, they are the inspectors' work benches, especially where the inspection demand requires larger sizes. And as a consequence also, many inspectors are inclined to keep them littered with micrometers, calipers, gage block accessories, pencils, workpieces, screwdrivers, pliers, clamps, finger rings, rags and what not.

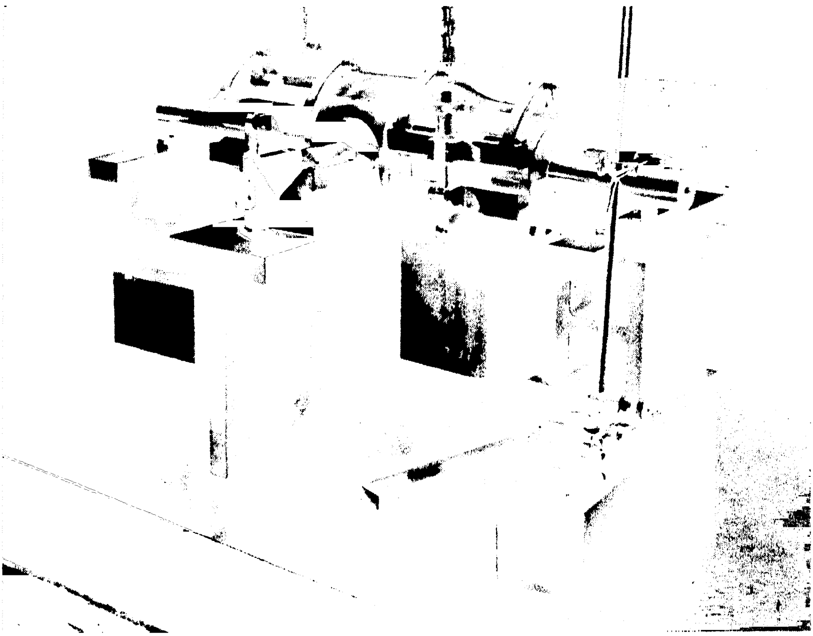
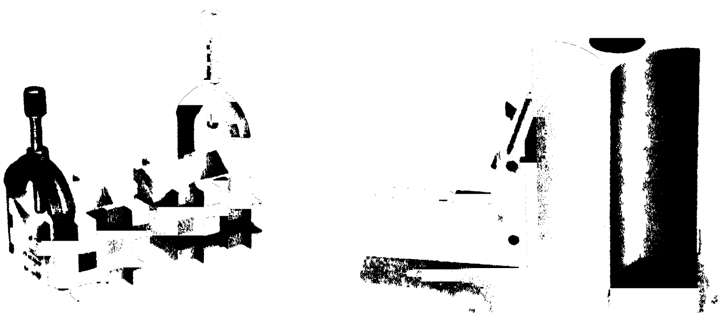


FIG. 9. Surface plate and various surface plate accessories.

Put on the surface plate at any one time only what is needed for the measurement immediately required. Don't drop everything on it because it's a handy surface; use the bench top beside it. The measurement may require a dozen pieces of apparatus anyway; there's no need of adding to the confusion. And, remembering that the surface is supposed to be flat and true to about .0001 inch, use slow, careful motions in setting apparatus down on it.

Any surface plate should be provided with a felt lined, wooden cover, like an inverted shallow box or the equivalent, to set down over the surface of the plate every minute it is not in use. A surface plate left uncovered, exposed, on bench or stand, and bare of any routine apparatus, becomes a magnet for anything anyone wants to put down. In no time at all, in the average shop, its surface will be loaded with packages, pieces of stock, the mail boy's bag, somebody's shoes or almost anything else imaginable. All this though the bench it rests on is entirely empty. Keep the cover on the plate to take the gaff.

In general, the same precautions in regard to maintenance and care described previously for gage blocks apply to surface plates. Try to prevent the edges of a surface plate from becoming nicked. Watch for corrosion and rust spots on iron surface plates. Clean the surface at each use and rust proof the surface for storage. Don't leave apparatus or metal objects on the surface longer than necessary and certainly not overnight.



Courtesy of Brown & Sharpe Mfg Co

Fig. 10 Surface plate accessories: (Left) V-blocks; (Right) Toolmaker's surface-plate square.

Surface Plate Accessories

Mention of surface plates always brings to mind the conventional types of apparatus and accessories more commonly used on and with them — knees, cubes or box parallels, V-blocks, parallels, squares, planer gages, height gages, test sets and many other articles. Some of these items appear in Figs. 9 and 10. They are all intended to make the job easier and the measurement more accurate or possible. The set-ups

in Fig. 11 show the practical use of some of these accessories. It would take an entire book to discuss surface plate techniques in detail and to educate fully a person in their use. Every shop has different problems; there are manifold shapes and sizes of components and parts, and about as many clever ways of handling their measurement. In regard to surface plate methods there are as many diverse, sometimes sharp, opinions as there are experienced inspectors, engineers, tool-

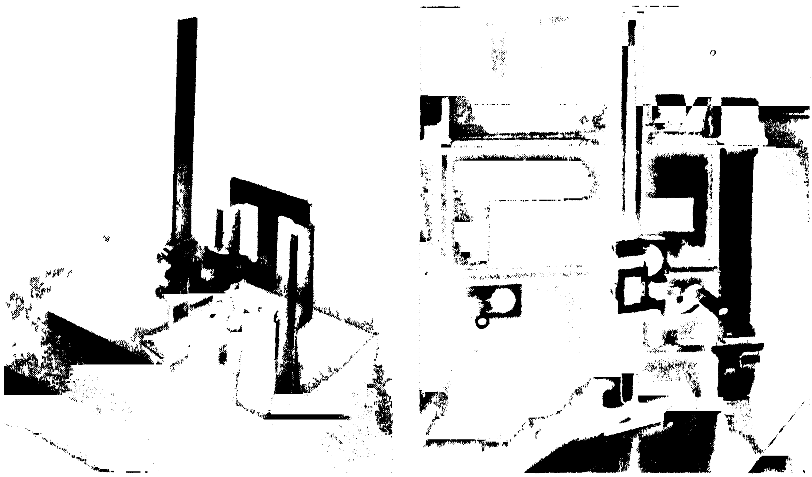


Fig. 11. Measuring devices being used The surface plate provides a reference plane

makers and seasoned mechanics. Perhaps, in the face of a problem of such magnitude, the best a book of this sort can do is to demonstrate and impress a few basic principles — a little geometry — and the best the new inspector can do is to observe and learn from experience; to use all the ingenuity and common sense he possesses when he is setting up at a surface plate.

Basic Principles of Surface Plate Use

Always remember, in using a surface plate, that the basic intention is to secure, geometrically, vertical and horizontal axes. The workpiece to be measured and the instruments and accessories used are manipulated, placed or clamped to effect this up-and-down and lying-flat idea. As a general thing, too, all measurements are read or taken from the surface plate up.

An attempt will be made to illustrate these general principles simply with a few diagrammatic sketches. As an example, study the workpiece sketched in Fig. 12 — a shaft with two threaded ends. The inspector is to check the dimension *d* which is to be machined, according to the blue print, to a length tolerance of ± .001 inch.

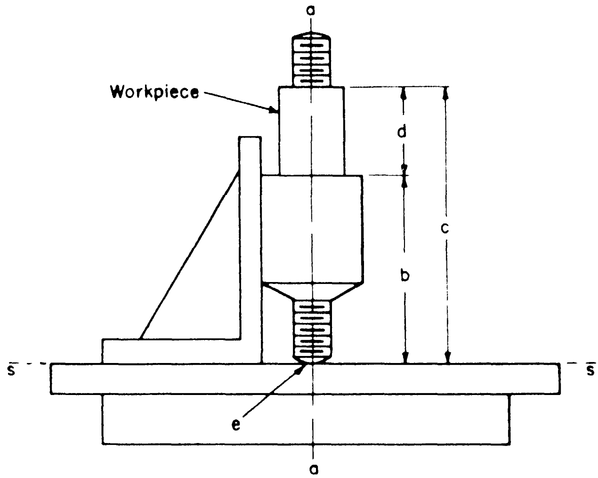


Fig. 12. Dimension *d* of the work-piece is obtained by measuring the distances *b* and *c* with respect to the surface plate and then subtracting *b* from *c*.

Dimension *d* might be checked with a steel rule, except that the tolerance is ± .001 inch, which is below the discrimination (.015 inch) of a steel rule. There seems to be no combination of standard commercial vernier caliper or micrometer — no mongrel combination of inside and outside jaw — with which *d* could be measured directly to any such accuracy as ± .001 inch.* A depth vernier or micrometer might be considered but, if the shaft shoulders were more shallow than half the width of the depth instrument anvil or base, a true measurement could not be readily secured. Besides, ordinary clumsiness in trying to use a depth gage on such a combination would make

* Where the production quantities of pieces of this general type warrant the expense of a specially designed indicating gage, the direct, accurate, and quick measurement of a dimension like *d* is readily secured as will be seen in the descriptions of modern indicating gage designs found farther on.

accuracies within ± .001 inch doubtful. To measure from the shaft end *e* to both shaft shoulders with vernier calipers sounds feasible except that the rough, rounded-off, threaded end of *e* is too insecure as a reference surface for ± .001 inch tolerances. And again, if the shaft shoulders between which the measurement is to be taken are shallow and if some portion of the shaft between these shoulders has a radius greater than the throat depth of the caliper, then the resulting interference would prevent a true measurement.

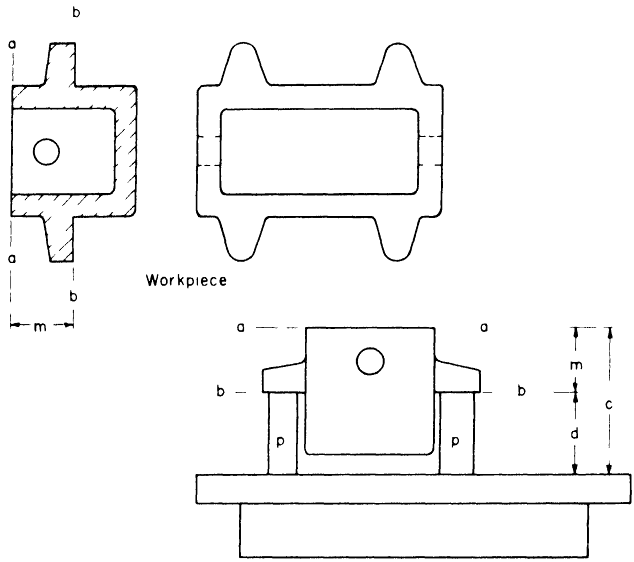


Fig. 13. This use of a surface plate facilitates measuring dimension *m* of the casting.

When the shaft is set up on a surface plate, however, as shown in Fig. 12, the measurement becomes simpler. The trouble with the irregular spherical end *e* is overcome by holding or clamping the shaft vertically against a machinist's knee. Thus, we get true perpendicularity between the shaft axis, *a-a*, and the flat plane of the surface plate, *s-s*, making sure, with a try square, that the shaft is not tipped forward or backward from true perpendicularity in the other plane. The next step, then, is to get measurements *b* and *c* (most likely with a height gage — see farther on) and, by subtraction, the desired dimension *d*.

Typical Surface Plate Inspection Problems

Suppose the inspector's next problem is to check the machining on a casting, typical of automotive transmission castings, shown diagrammatically in Fig. 13 where the top surface *a-a* has been planed off; likewise the under surface of the lugs, *b-b*. No other machining has been done; the exterior and interior of the casting, other than the surface *a-a* and *b-b* are as rough and unfinished as when they emerged from the foundry mold. Dimension *m* is "critical" because the cored

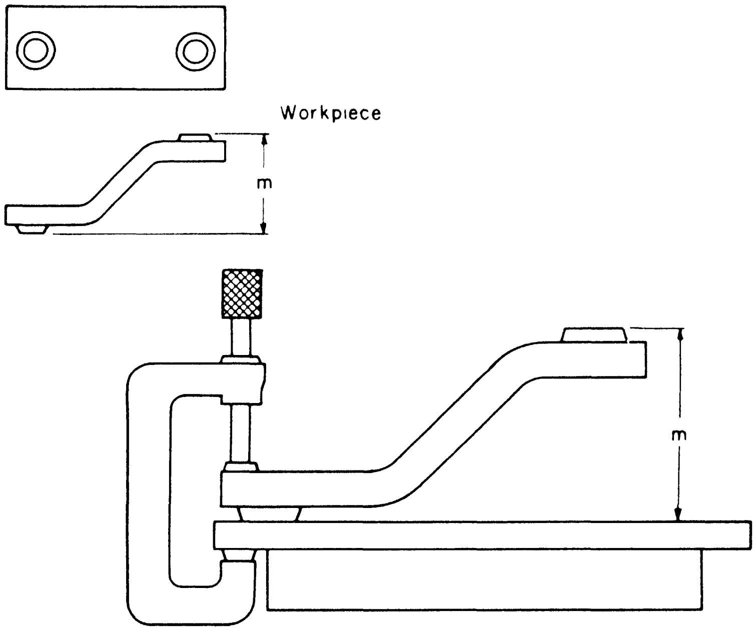


Fig. 14. Dimension *m* is easily measured if one leg of the S-shaped work-piece is clamped against a surface plate.

holes in the casting must be bored out eventually to line up exactly with and be a certain distance above another set of holes in another casting to which the workpiece lugs (*b-b*) will be bolted when it reaches the assembly line. The tolerance is again ± .001 inch for dimension *m*.

As Fig. 13 shows, the surface plate plus a pair of steel parallels, *p-p*, make light of getting dimension *m*. In fact, after the casting is rested on the parallels, only dimension *c* need be taken (again, likely, with a height gage) because

dimension *d* is known — the height of the parallels, *p-p* stamped on them.* Dimension *m* of course is dimension *d* subtracted from measurement *c*.

To illustrate the facility of surface plate techniques, try to figure out how you would get measurement *m* on an S-shaped piece, like the workpiece sketched in Fig. 14, by means of any of the sort of measuring apparatus described previously. Figure 14 shows how simple the measurement becomes if one leg of the S-shaped piece is held down firmly on a surface plate.

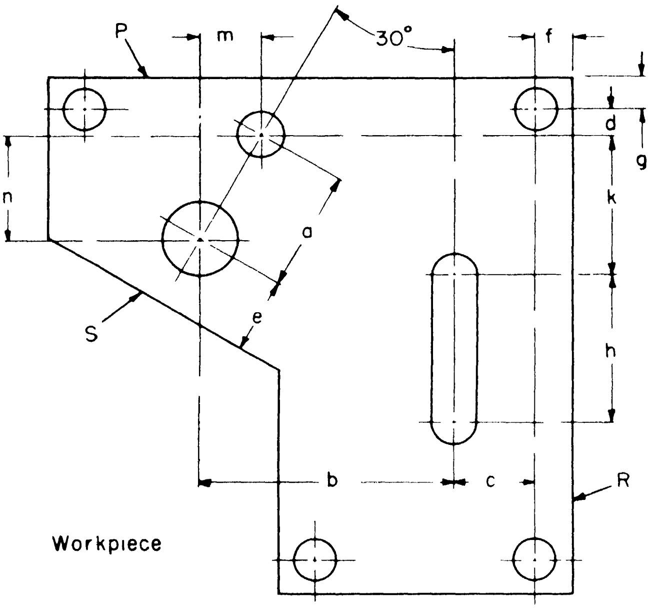


Fig. 15. Flat work-piece showing various dimensions that must be measured or calculated from other measurements.

The ease with which surface-plate setups can many times pick difficult measurements "out of the air" is illustrated even in the rather simple problem of Fig. 15. The relevant dimen-

* This assumption brings up another word of warning. All surface plate accessories should be checked regularly to be sure their measurements correspond to the legends stamped on them. If the parallels in this particular example were stamped, for instance, 1½"x3", the 3-inch height, and the parallelism itself, of each of the steel parallels should be checked independently before they are used on the surface plate. Any inaccuracies should not exceed .0005 inch.

sions supplied for this workpiece layout by the draftsmen are shown as letters *a* to *h*, plus *k*, along with the 30-degree angle. The question is: Did the mechanic lay out the hole centers and the slot correctly to tolerances of ± .001 inch?

Checking Hole and Slot Positions

Figure 15 shows the workpiece in the position it appears in on the blueprint. Notice dimensions *f* and *g* in the upper right hand corner. The assumption is made that the machinist, in laying out, drilling or jigging the workpiece plate followed the draftsman's suggestion with *f* and *g* to the extent that sides *P* and *R* were the reference surfaces from which he worked.

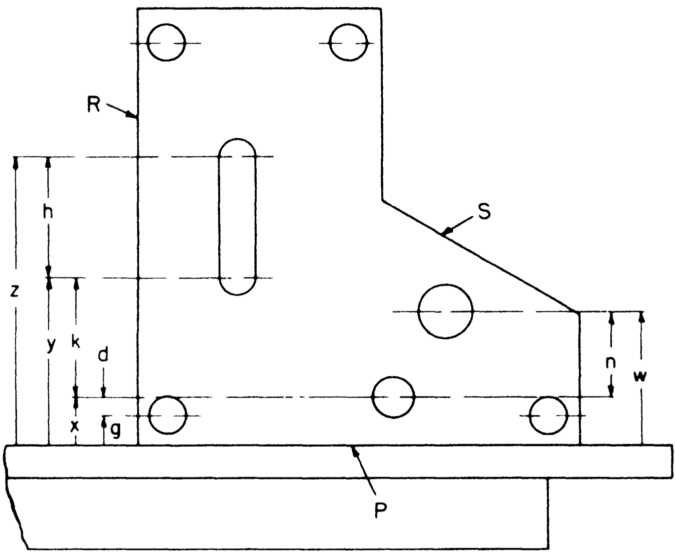


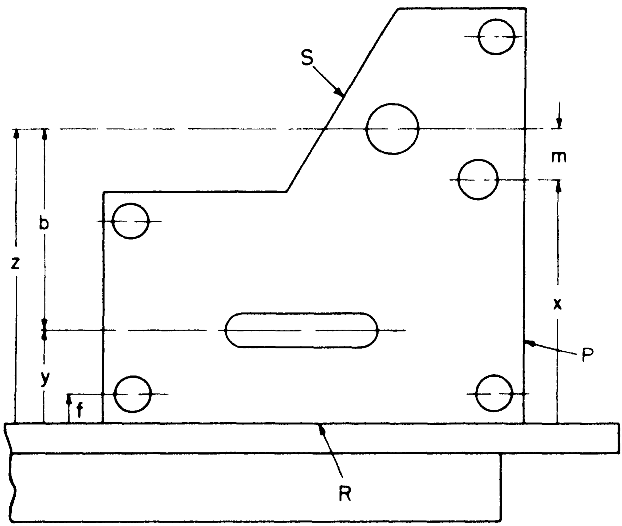
Fig. 16. (A) Work-piece of Fig. 15 with reference surface *P* placed on surface plate. The various dimensions indicated are then determined by measurement and calculation.

The professional touch in surface-plate work is illustrated in the diagrams of Fig. 16. Set up the work so that a number of dimensions are vertical to the surface plate plane. After measuring these, the workpiece is then located so that the normally horizontal dimensions are vertical, etc. In this case, since surface *P* is the reference surface for the dimensions

showing vertically on the blue print and since we measure always from the bottom up on a surface plate, the workpiece is turned over or completely around so reference surface *P* rests on the surface plate as Fig. 16-A indicates.

In setting up and measuring, maintain the usual precautions of freeing the workpiece of dirt, chips and burrs that might prevent its being squarely clamped.

Only the center lines relevant to the vertical measurements to be taken in this position are shown in Fig. 16-A. The diagram is made thus, purposely, to point out how the inspector's



B

Fig. 16. (B) Work-piece rotated 90 degrees from position shown in Fig. 16. (*A*). Dimensions indicated are obtained by measurement and calculation.

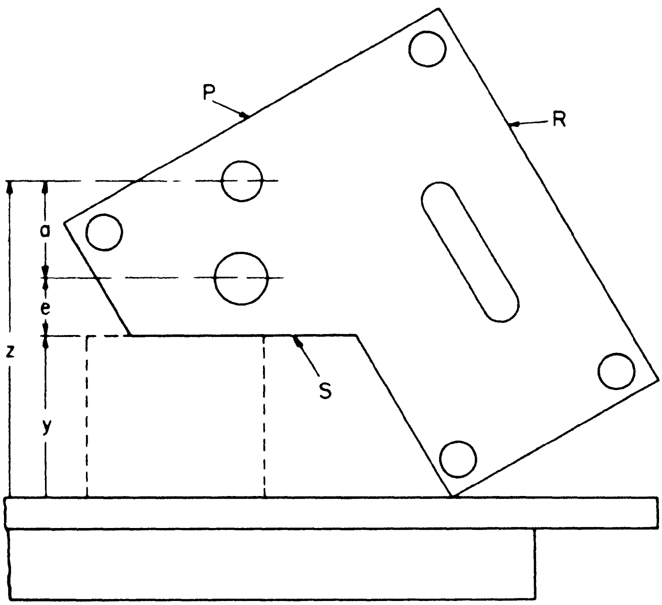
mind unravels from the blue print (which in Fig. 15 is represented by the sketch of the workpiece) only the dimensions he wants to measure in any one setting. So, he proceeds to measure *g*, *w*, *x*, *y* and *z*. From these, with pencil and paper and subtraction, he can determine dimensions *d*, *h*, and *k*.

But notice dimension *n* both on Fig. 16-A and on the workpiece sketch in Fig. 15. The thorough inspector would get out his trig book and figure out from the dimension *a* and the 30-degree angle what dimensions *m* and *n* in Fig. 14 should be and check them also. Dimensions *m* and *n* did not appear,

of course, on the blueprint. They were added to the workpiece sketch of Fig. 15 to bring up the point that hole coordinates, so-called, should be checked two ways, especially where an angle is involved.

Incidentally also, the inspector assumes that the centers of the other three holes in the corners of the workpiece, for which no dimensioning appears on the blue print, bear the *f* and *g* relationship to their respective sides even though the draftsman failed to include specific *f*'s and *g*'s for the other three holes.

In a similar manner, Fig. 16-B, the workpiece is turned again so that what were horizontal dimensions on the workpiece sketch are now arranged vertically for ready surface plate measurement. In this position, dimension *m* is also checked, following the thinking in connection with *n* mentioned in a previous paragraph.



C

Fig. 16. (C) Work-piece positioned so that the remaining dimensions may be measured and calculated.

Finally the workpiece is turned at a 30-degree angle, Fig. 16-C, so that surface *S* is now horizontal. This position permits

the ready measurement of dimensions a and e which, on the workpiece sketch of the actual blue print, appeared as diagonals.

In the preceding examples, it has been shown that the basic surface-plate technique of measuring is always perpendicularly upward from the horizontal plane of the surface plate as a general reference surface.

Accessories for Checking Hole Location

The discussion of Fig. 15, thus far, has taken into account only the simple geometry involved. The next question, of course, is how, actually and physically, the several measurements are to be secured. When it is necessary to measure the location or coordinates of a hole, the customary technique is to "plug" the hole. The idea of plugging a hole and measuring

Fig. 17. Measuring the center distance of two holes by "plugging" the holes and measuring over the plugs

hole centers by getting, actually, the location of the circumference of the hole is illustrated in Figs. 17 and 18. Figure 17 shows how a simple measurement could be secured with micrometers or vernier calipers and Fig. 18 shows the use of a height gage equipped with a dial indicator.

These illustrations also show a favorite device — the use of standard plug gages for plugging holes. Another possibility, not thought of often enough in this connection and consequently not used for plugging holes as much as it could be, is the correct combination of tapered parallels such as are illustrated in Fig. 23, Chapter 6. For many measurement conditions where tolerance requirements are not too precise, drill

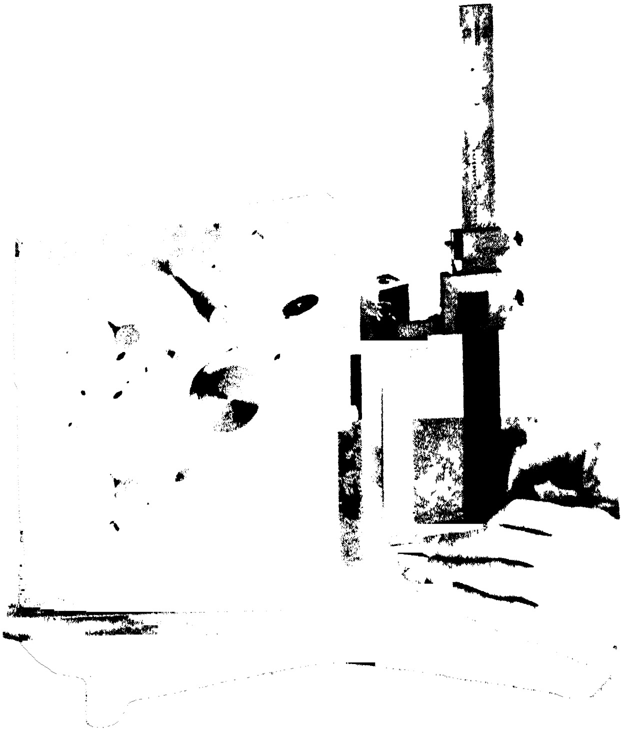


Fig 18 Measuring the position of a hole by using a stack of gage blocks, a vernier height gage, and a plug.

rod or drill blanks form satisfactory and frequently readily available plugs. A number of commercial tool and gage manufacturers supply wire plug gages, taper inserts and measuring rolls. Sometimes the measuring stint is sufficiently worth having the inspector's own tool room or machine shop turn and grind the necessary sizes and sets of hole plugs.

Whatever is used as an auxiliary for securing hole location

or hole-center coordinates in a surface plate setup, there are several routine precautions in the direction of greater precision that the inspector should observe. Item number one, the inspector should measure accurately the diameter (the O.D.) of any plug he is about to use. His problem is to measure to the center line of the hole. Actually he measures to the outside diameter of the close fitting plug and *subtracts* from this measurement half the diameter of the plug to get the distance to the hole center line.

The surface of the plug should be smooth. When the edges or interior of the hole to be plugged for coordinate measurement are unnecessarily burred and rough, it is frequently wise to smooth off excess metal with crocus cloth.

The plug should be selected and measured so that its diameter in relation to the hole diameter will yield a firm fit — something akin to a wringing fit — when the plug is inserted. The inspector should be unable to rock, shake or turn the plug, after it is inserted in the hole, with normal gaging pressure. If either the plug or the hole is out-of-round, as shown at A or B in Fig. 19, errors in measurement will result. The condition shown at C in Fig. 19, where a true plug contacts an oval hole along its vertical axis is not as undesirable as A or B.

In the same general manner, the use of tapered plugs and the presence of tapered holes can produce errors in securing the coordinates of holes. When measuring a plug for its diameter (O.D. size), check its periphery also for out-of-round and taper. Check the hole likewise. The conditions implied are exaggerated in diagrams D and E of Fig. 19.

Many inspection departments allow — even establish as a routine — the definite use of tapered plugs. If a plug with a slight, uniform taper is used it will of course wedge in the hole and give the effect of a wringing fit because the metal around the hole is slightly and probably evenly expanded. Properly done, such a procedure will not affect the accurate securing of the hole-center location enough to make material difference. Nevertheless the condition pictured in E of Fig. 19 remains present. Suppose the diameter of the plug itself is measured as lines *a-a* in sketch E of Fig. 19 indicate and suppose the surface-plate measurement for the hole location happens to be made as *b*. Subtracting half of *a-a* from surface

plate measurement *b*, it can be readily seen, will yield an error in recording the actual hole axis vertical coordinate. The practical rule does not forbid the use of uniformly tapered inserts, but the total taper of the plug itself should not be greater than, say, one-tenth of the tolerance or specification for the hole-center location being measured.

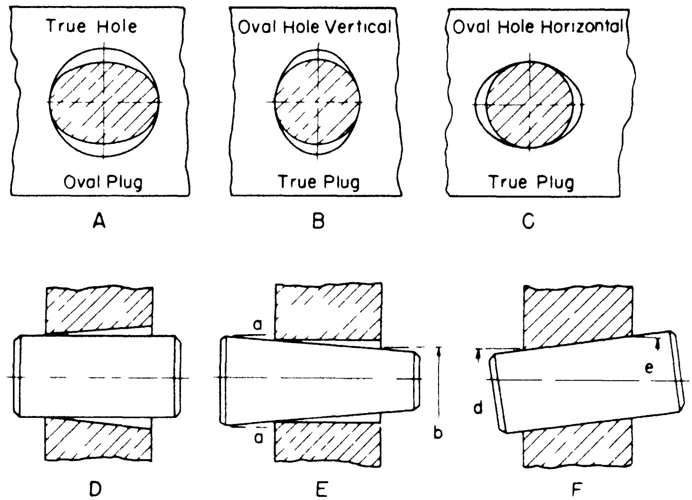


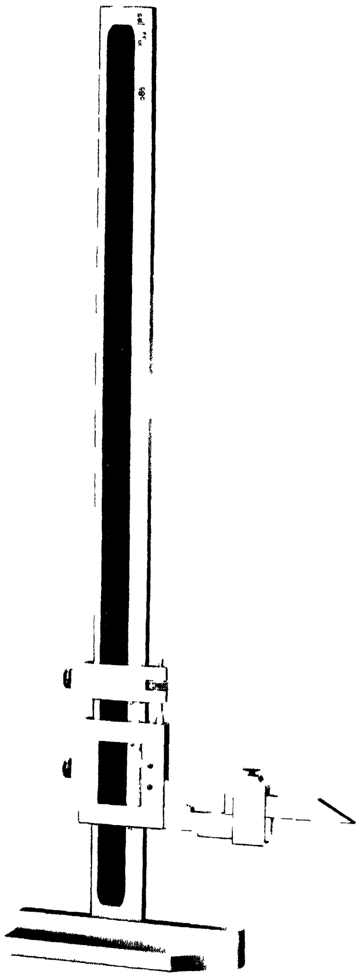
Fig 19. (A through F) Various conditions of fit between a hole and measuring plug that result in erroneous measurements.

Where the center-line of the hole is not parallel to the plane of the surface plate, another, but generally similar, error can be introduced. The inserted plug will be tipped as portrayed in the exaggerated diagram of F in Fig. 19. If half the diameter of the plug is subtracted from either measurement *d* or *e*, sketch F, as taken from a surface plate, it is quite apparent that the true location of the hole center will not be obtained.

Sometimes it is necessary to establish the distances between hole centers or locate their coordinates under conditions where the axes of the holes are deliberately, by design and blue print, at an angle with the horizontal, perpendicular or normal. If precision in terms of, say, .0005 inch is required, or if the angles of the hole axes exceed several degrees, the geometry of measuring tapered plugs with measuring rolls can be applied — with a little ingenuity and trigonometry. This technique will be taken up farther on in Chapter 13.

The Height Gage

As a rough analogy, the height gage is to the surface plate what butter is to bread — you seldom think of one without the other. Like the other members of its family, the vernier caliper and the vernier depth gage, it has primarily a graduated beam and a sliding frame with a vernier scale as shown in Fig. 20. It is mainly different from its family because of the foot block or base which supports the vertical beam and which adapts the height gage to direct use with a surface plate or on any smooth, truly flat surface.



Courtesy of Brown & Sharpe Mfg. Co.

Fig. 20. Height gage equipped with a vernier scale.

Even though the height gage seems almost entirely different from the vernier caliper, the basic resemblance, the basic principle, is present nevertheless. In the case of the height gage, its base *plus* the surface plate are the equivalent of the fixed or solid jaw of the vernier caliper. The movable or sliding arm of the height gage differs from the similar member on the caliper only in a few mechanical details which include accessories for making surface plate measurements easier. In other words, between the surface plate on which the height-gage foot block rests, and the sliding arm of the height gage, there is the general C-frame principle of the vernier caliper with a reference jaw, literally the surface plate, and the adjustable measuring jaw on the gage itself.

In the case of the height gage, however, the vertical beam

Fig. 21. Measuring a work-piece dimension using a vernier height gage equipped with a scriber point attachment.

is so graduated and calibrated, in relation to the under side of the base or foot block, that the correct vernier reading records the actual height to surface *s* of the extension arm *a* as shown in Fig. 22. To put this another way, the height gage's scale and vernier give a direct reading (correct to a possible .001-inch instrument error) of height above the surface plate, such as measurement *c* in Fig. 22, where the standard, so-called scriber point attachment is used on the extension arm *a*. Figure 21 shows this sort of measurement which is, in the larger sense, "calipering."

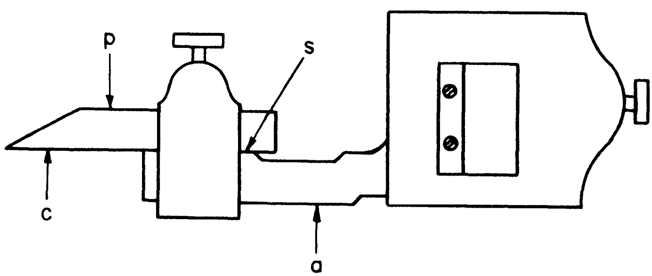


Fig. 22. Diagram showing the various components of a scriber point attachment.

Checking the Height Gage for Accuracy

Before a height gage is used, the common checks for instrument accuracy, wear and looseness should be made as generally described in the previous section for vernier calipers. Certainly, arm *a*, Fig. 22, should be perpendicular to the main vertical beam of the height gage when the sliding vernier frame is clamped tight against the beam. An experienced inspector, using a height gage strange to him, will first check for any looseness or play where the vertical beam is fastened into the foot block.

The important section of the height gage, from the point of view of instrument condition, is the under side of the foot block or base. This surface originally is machined flat, true, smooth and unwarped to within a few millionths of an inch of a perfect plane surface.

As with gage block surfaces, examine the height gage base measuring surface for scratches, nicks, corrosion or any other damage. (Once in a while examine the solid junction of the vertical beam with the base for strain cracks, especially if the gage has been dropped or if some amateur has used the gage for a hammer.) After setting the height gage on the surface plate, press down on the base with light but firm finger tip pressure and try to rock the gage. Try rocking it from several different angles. There should be no perceptible feeling of instability; in fact, sliding the base a little bit on the test flat should yield a slight sensation of wringing. Some mechanics occasionally tip the height gage upside down and indicate across the measuring surface or underside of the foot block (a principle described more in detail in a section farther on) or, more rarely, make a surface check with an optical flat. Where it can be seen that the condition of the under surface of a height gage might produce a measuring error greater than .0002-inch, the instrument should be turned in for reconditioning.

A height gage's full scale accuracy can be calibrated step-by-step by setting it up and checking vernier and beam graduations at several different stations along the vertical beam against the heights of gage-block stacks.

The height gage 0 check is made by sliding the arm *a*, Fig. 22, and the vernier bracket down to the base. In this position the vertical distance between the surface plate and the surface *c*, the under side of the scriber point attachment *p*, is sup-

posed to be one inch. Check this space with a 1-inch gage block and, simultaneously, the vernier reading on the beam which should be, of course, 1 inch. The graduations on the height gage read directly the height of surface *s*, above the base or the surface plate the gage rests on. Where elevations less than 1 inch must be measured, the height gage is provided with an offset attachment, such as is illustrated in Fig. 23. Using the offset attachment in the position shown,

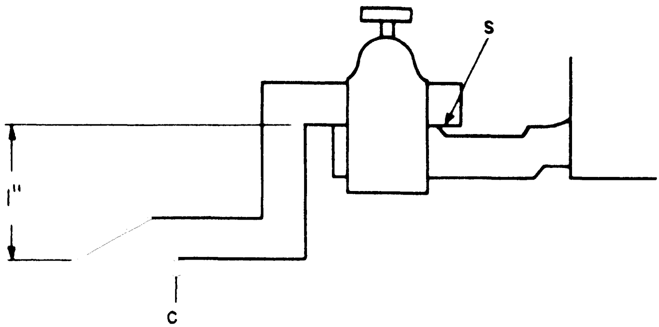


Fig. 23. Offset attachment used with a vernier height gage for height measurements of less than 1 inch.

the readings for height are made between the 1-inch and 2-inch graduations on the height gage beam and 1 inch is subtracted from each such reading in order to secure the correct figure for the actual height measurement between 0 inch to 1 inch. All this, because the offset attachment's measuring surface *c*, Fig. 23, is purposely made 1 inch below the clamping surface *s* in contact with arm *a* of the gage.

Accessories Should Also be Checked

A height gage is probably never used without having some accessory or attachment clamped to its measuring arm — a scriber point or offset, a depth attachment or an indicator. These accessories must be examined regularly, as independent units, for such errors as lack of parallelism, taper, wear, corrosion, warp or curvature. All clamps, springs, gibs and screws should be kept in shape and replaced when worn or loose. When a calibration check on a height gage shows an appreciable error, suspect the condition of attachments, accessories and clamps first before attempting to adjust for calibration errors at the vernier scale.

It is difficult within the limitations of static print and photographs to describe to the neophyte the actual, practical use of such a generally mobile instrument as a height gage. Some of its applications will appear farther on, either directly or incidental to descriptions of other instruments, apparatus, measuring techniques and inspection methods. The best school for height gage instruction is at a surface plate, machine or bench with workpieces requiring measurement. The coaching of an experienced inspector or skilled mechanic helps, of course. Every instructor, it will be found, has certain ingenious methods of his own plus likely sharp disagreements with the techniques of others. A few pointers, however, can be offered here which will help the amateur when he first uses a height gage.

Care and Use of the Height Gage

In the ordinary shop there is too much tendency to leave a height gage kicking around. When it's not in use, put it back in its box. Too many times we take it off the surface plate and stand it upright on a gritty dirty bench top. At least it could be rested gently on its side and thus protect the smooth flat under surface of the base.

Naturally, be sure this latter surface is carefully cleaned each time the height gage is used. Also clean the surface of the plate or machine where it is to be used. This is only reemphasizing all the general rules for instrument care which have been expressed and described thus far. Then, always move a height gage slowly, gently; don't slam it around. Don't let the base of a height gage inadvertently dig, scratch or shave the surface of a surface plate.

Theoretically the base of the height gage should wring to the surface plate. Practically, of course, this is impossible because the most useful feature of a height gage is its sliding along on a plane, level, flat surface. Skill and practice in its use does produce a slight suction or wringing sensation, a slight drag, discernible at the finger tips. If these effects are not present at least to a small degree, look for dust, grit, scratches or excess oil on the gage and plate surfaces. Perhaps the gage base or the surface plate is warped, curved or worn. Perhaps, too, the gage is being imperceptibly, and unconsciously, tipped, tilted or rocked.

Standard gaging pressure, 8 ounces to 2 pounds, is used in

sliding a height gage along a surface plate and especially as an arm extension slides over the workpiece surface or, say, the outside diameter of a plug when measuring for hole coordinates. Read again the warnings (page 94) concerning the unconscious and imperceptible tipping, canting and lifting of a depth gage base. The same principle applies here. Always remember not only to slide the height gage forward and back, but also to keep pushing downward on the base with firm though light and constant pressure. The experienced mechanic rechecks every reading and measurement made with a height gage by sliding the measuring arm over the workpiece surface at least twice. If he gets repetition (a repeated reading), he feels that his setting and manipulation are correct.

Accuracy Expected in Height Gage Measurements

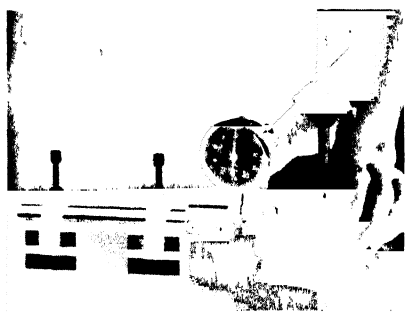
An accuracy in reading can be expected of a height gage to .001 inch, probably not much better. (Where an indicator with a discrimination to .0001 inch is used on the height gage, accuracies greater than .001 inch are of course, obtained.) Height gages come, commercially, 10 inches, 18 inches and 24 inches in height. The taller the gage the greater must be the care taken concerning tilting, and in pressures and wringing effect to secure accurate readings. The repetition test is a safe test of manipulation. However, the manufacturers of height gages do not guarantee the extension of .001-inch accuracy to the upper ends of the 18-inch and 24-inch gages; an allowance up to .002 inch may have to be expected in the longer gages.

The question of instrument temperature and expansion probably enters less in the use of a height gage than with most other measuring instruments. This is because, professionally, the height gage is always manipulated by its base as generally indicated in Fig. 21. Only the amateur grasps the height gage up along the beam. The only reason for holding the beam, and expanding its length by heat transfer from the hands to the beam, is generally when the vernier slider is being set and clamped for a measurement or when the height gage is picked up in order to read the graduations on beam and vernier. If the measurement involved is fairly precise, and if you realize you are handling the gage rather steadily, it is wise to let it rest untouched on the surface plate for a few minutes to let the effects of temperature subside. Like other measuring instruments, a height gage and surface plate

should not be used in direct sunlight, too close to a hot radiator nor in a direct draft.

V-Blocks

V-blocks are essentially tool steel blocks that are very precisely 4-square. As Fig. 24 indicates, they usually have two V's, one sometimes deeper and wider than the other. Channels are cut in either side to accommodate special holding down clamps as illustrated. Standard V-blocks come as 45-degree blocks, i.e. the V-sides slope 45 degrees from horizontal or vertical, the included angle of the V being, of course, 90 degrees. Because they are made with sides and ends parallel and/or square to each other, they may be used lying flat, as shown in Fig. 25, or turned over on their sides, or up-ended



Courtesy of Brown & Sharpe Mfg Co

Fig. 24. (Left) A pair of precision V-blocks with work-holding clamps.
Fig. 25. (Right) A pair of V-blocks being used to facilitate measurement of a work-piece dimension.

vertically. For special purposes such as checking triangle effect or for taps and other three-fluted tools, 60-degree V-blocks can be secured. The included angle of the V then is 120 degrees.

The major purpose of V-blocks is to hold cylindrical pieces or, more to the point, to establish precisely the center line or axis of a cylindrical piece. Understanding the V-block is a matter of a little geometry.

When a cylindrical piece rests in a V-block it takes the position shown diagrammatically in Fig. 26. From the point of view of geometry, the figure is a circle touching or tangent to two sides of an angle. Therefore, radii of the circle, lines *a-c* and *b-c*, extended to the point of tangency, are perpendicular

to the sides of the included angle and angle d will equal angle e or angle f will equal angle g. Conversely then, where a circle touches two sides of an angle, lines drawn perpendicular to the sides of the angle from the point of tangency will intersect at the center of the circle. A line drawn through the center of the circle and the vertex of the angle will bisect the angle included between the tangents.

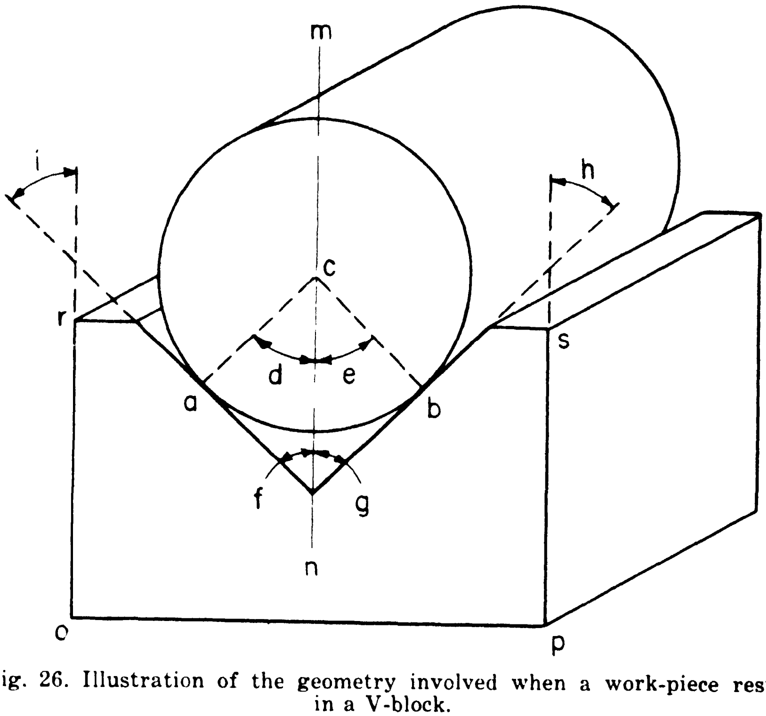


Fig. 26. Illustration of the geometry involved when a work-piece rests in a V-block.

In mechanical terms, the V-block "finds the center-line" of the circular section or, to put it another way, it locates the cylinder so that its vertical diameter passes through the vertex of the V as shown in Fig. 26. If the V-block of Fig. 26 is on a surface plate, the center line (m-n) of the cylinder is perpendicular to the surface plate plane. At the same time, of course, the cylinder's center line, m-n, is perpendicular always to the base of the V-block, o-p, and always parallel to its sides o-r and p-s, provided the V-block is made not only 4-square, as it should be, but also with angles f, g, h, and i all equal.

Checking the V-Block for Accuracy

In ordinarily using a V-block, first check it visually, or with the finger nail, for dents, edge nicks, scratches and burrs which might either damage the surface plate or cause the V-block to tilt imperceptibly from true flat or vertical. Be careful not to let it drop on the surface plate. V-blocks are heavy, solid and sharp cornered; they slip out of the fingers readily.

Any V-block should be checked periodically for basic accuracy. If it has rusted; if it is worn; if it has warped a little; if it were made inaccurately in the first place; its four sides and two ends may not be truly parallel or square to each other. The V-channel may be out of parallel. Constant use with the same size cylindrical workpieces wears hollows in the V-sides. Some of the possible types of inaccuracies discoverable in a V-block are indicated by the light dotted lines in the sketch of Fig. 27. Probably the best way to check a

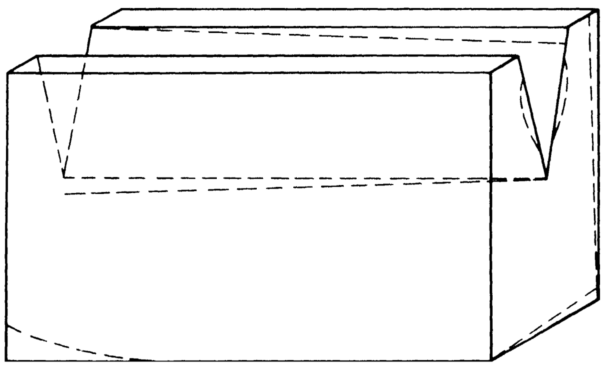


Fig. 27. Various inaccuracies which may exist in a V-block.

V-block's accuracy is to "explore" with an indicator test set, a technique which is to be described in a section farther on devoted to the subject.

The same general principle of watchfulness in connection with nicks, burrs, scratches, corrosion etc. applies of course to parallels, cubes, knees, cylinder squares and all other surface-plate accessories.

Earlier sections have discussed the conditions to be found on cylindrical workpieces which spoil their true geometrical shape, conditions, such as out-of-round or taper. The eccen-

tricity or lack of concentricity, between two adjacent cylindrical sections has beeen described. The V-block is most useful probably for discovering inherent defects of this general type.

Figure 28, shows the general technique for using a height gage over a piston resting in a V-block. If taper is suspected, run the height gage arm over the workpiece as Fig. 28 suggests.

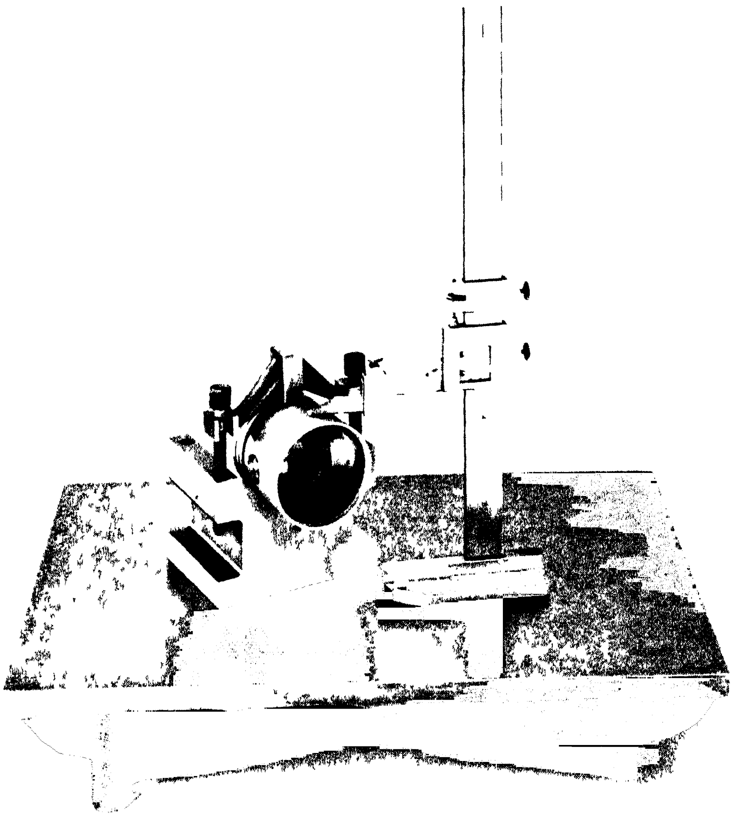
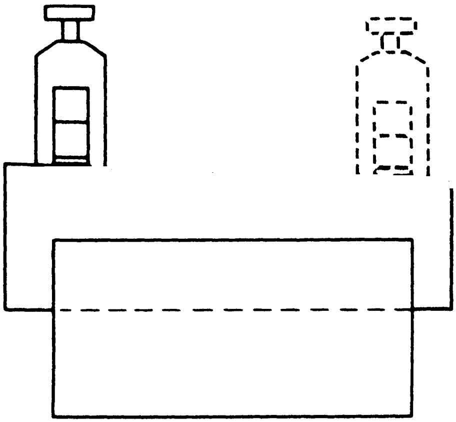


Fig. 28. Checking the taper of a piston that is resting in a V-block.

gests. Let the vernier slider down until the height gage arm attachment touches the workpiece surface and tighten up the fine adjustment clamp. Then, using the fine adjustment screw, move the arm up or down, at the same time sliding the height gage back and forth with firm downward pressure on the

height gage base, until the height gage arm seems to be at an adjustment where about a half pound of lateral gaging pressure is necessary to "rub" the arm over the workpiece. Clamp the vernier slide and check for repeat reading, and read the scale. Then move the height gage along the length of the workpiece cylinder so that two separate measurements are taken as shown in Fig. 29.

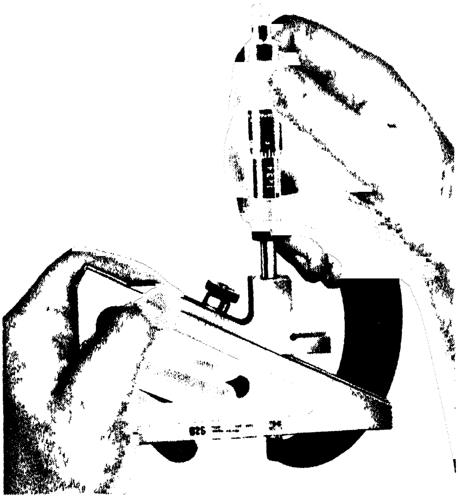


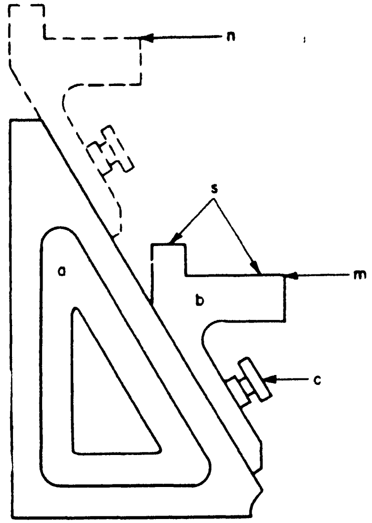
Courtesy of Brown & Sharpe Mfg. Co.

Fig. 29. Two separate measurements taken on work-piece of Fig. 28 will indicate the amount of taper.

The Planer Gage

Another piece of equipment that may be used in conjunction with a surface plate is the planer gage, Fig. 30. The planer gage consists primarily of two triangular shaped blocks whose sloping sides can be clamped together. Geometrically it is somewhat akin in principle to tapered parallels. Its main member or base, *a* in Fig. 31, is a 30-, 60-, 90-degree triangle that can be stood on its long leg or the short one. The sliding and clamping member, *b*, can be slid along the hypotenuse of the triangle, *a*, and clamped in any position with the clamp screw *c*. Such action moves the surfaces *s* vertically up or down to the desired height, surfaces *s* always maintaining a horizontal position — always remaining parallel to the surface plate plane on which the planer gage stands. It is then a convenient and quick way of securing variable heights above a surface plate as illustrated diagrammatically in positions *m* and *n* in Fig. 31.





Courtesy of Brown & Sharpe Mfg Co

Fig. 30. (Left) Planer gage, a tool often used with a surface plate.
Fig. 31. (Right) Component parts of a planer gage.

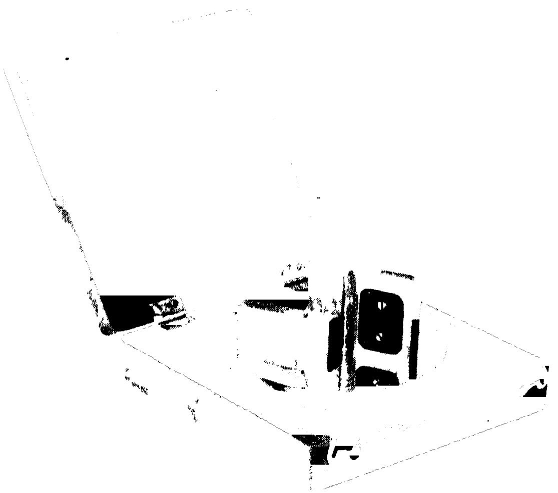
The Toolmakers' Flat

A small cousin of the surface plate is called the toolmakers' flat, machinist's flat or the optical flat. Commercially it is ordinarily a disc of special aged steel 5 or 6 inches in diameter, 3/4 to 1 inch thick, whose upper and lower surfaces are machined, ground and lapped smooth, polished, flat to .000010 inch, almost the accuracy of gage blocks. The two finished surfaces are usually guaranteed to be parallel to each other within .000010 inch. It is precision equipment and should always be kept in the velvet lined box it comes in. In fact, frequently, the measuring setup is accomplished on a toolmaker's flat while it is still in its box. Fig. 32 illustrates this apparatus.

If you will turn back to Fig. 6, which shows an 81-piece gage-block set with attachments, you will see a triangle base, so-called. This is essentially a gage-block attachment but can be used after the fashion of the toolmaker's flat. The triangle base is made to the precision described above for the toolmakers' flat. It is smaller, however, each side of the triangle shape being about 3 inches.

A toolmakers' flat or triangle base should receive constantly the same care and maintenance recommended for gage blocks.

They should always be carefully cleaned for use, and thoroughly rust proofed for storage. They require more care than gage blocks in handling because they are larger and heavier. If a toolmakers' flat is dropped, it is probably more or less ruined and should be returned to the manufacturer for resurfacing. Somehow too, it seems easier to gouge or scratch the surface of a toolmakers' flat with apparatus than almost any other piece of equipment.



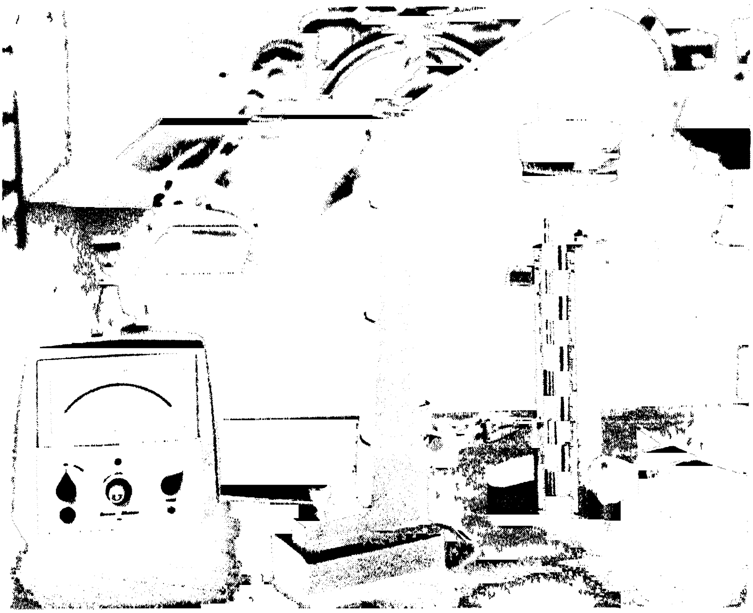
Courtesy of The Van Keuren Co

Fig. 32. Toolmakers' or optical flat in use. This is a high-precision surface plate.

Where a measuring setup calls for precisions down to .0001 inch or less, the toolmakers' flat should be selected. In other words, don't use it indiscriminately. If the blue print tolerances are greater, say, than .0005 inch for any measurement you need, don't be getting the triangle base or toolmakers' flat out. It is useless and inconsistent, for instance, to use a flat under a height gage unless an indicator with .0001 inch discrimination is also used and needed. If one is available, there is a temptation to use it oftener than the practical circumstance requires, the way a high school girl will always put on her newest and best dress for any occasion.

While flats are used directly as if they were miniature surface plates for certain precision setups where gage blocks,

V-blocks and height gages may be involved, probably they are best used on a surface plate to present local areas of extra precise flatness on which to rest a gage-block stack, V-block or indicating height gage. If an extra precise indicator and gage-block measurement is required and if the face of the surface plate is suspect for some reason, then the triangle base or toolmakers' flat forms a useful, even necessary, accessory.



Courtesy of Brown & Sharpe Mfg Co

Fig 33 With this height gage, settings can be taken from top or bottom of 1 0000-inch gage blocks spaced one inch apart

An interesting height gage design utilizes a number of precision blocks stacked alternately and supported by a carrier which is moved vertically by a micrometer head. Settings can be taken from either the top or bottom of any block (the blocks are exactly 1.0000 inch high) and the micrometer head permits settings in ten-thousandths of an inch over the entire range of the instrument. Thus, with a minimum of adjustment, a wide range of settings can be quickly and accurately obtained. Figure 33 shows this type of gage being used to check the height of the surface of a casting that has been ground.

CHAPTER 8

Mechanical Indicating Equipment

It is unlikely that an inspector would be long in a modern shop's inspection department before he became acquainted with test indicators, test sets, indicators and comparators. Perhaps his first step connected with indicating equipment would be the use of a test indicator on a height gage as shown

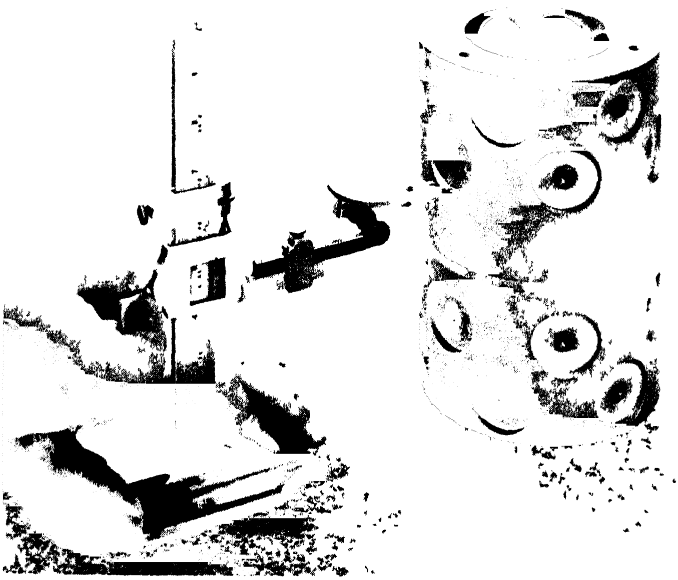
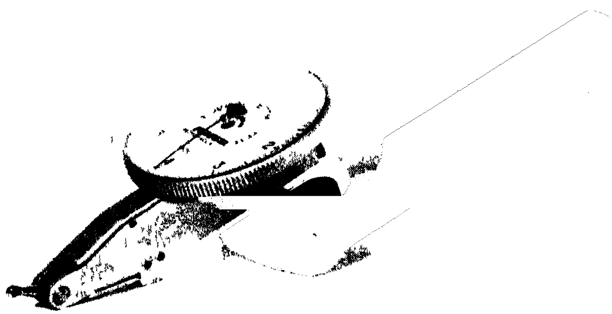


Fig. 1. Dial test indicator being used in conjunction with a height gage.

in Fig. 1. Test indicators are provided with clamp arms and attachments especially designed to fit the height gage measuring arm and clamp. Figure 2 shows a typical commercial test indicator and the universal swivel with which these instruments are usually equipped so that a test indicator may be cocked at almost any convenient angle or extended position.



Courtesy of Federal Products Corp

Fig. 2. Typical commercial test indicator equipped with a universal swivel.

Use of Test Indicator on Height Gage

Test indicators on height gages are especially useful in testing for out-of-round and taper. Look back at Fig. 28 in Chapter 7 and think of a test indicator clamped in the height gage rather than the scriber point. If the amount of taper is slight, the inspector might have trouble detecting it by pressure and "feel" with the solid scriber point, but a test indicator will translate a minute variation into visible readings on a dial. The indicator quickly and automatically displays the amount of taper in .001-inch or .0001-inch graduations, when it is desirable to know the degree of such errors, as compared to the much more tedious process of clamping and unclamping, adjusting and reading the conventional vernier device on the height gage. To say nothing of the accuracy gained. When an inspector uses a test indicator on a height gage, he is spared the dual chore of controlling the correct amount of gaging pressure applied to the object being mea-

sured plus the manipulation of the gage. He needs only to be sure the height gage base is in full flat contact with the surface plate — wringing it, as it were. The indicator does the rest, practically.

Checking for Various Shaft Conditions

Quite likely the most important service performed by the indicating height gage is the check of concentricity. In Chapter 7, see Fig. 12, the measurement of shaft shoulder lengths was described and illustrated. Suppose now it was desirable to know that one shaft section is concentric with the other (within definitely expressed specifications or, lacking them, within half the diameter tolerance.)

The first step is to indicate for ovality and taper; the second step to search for the evidence of a bent or bowed shaft. Any of these elements — ovality, taper, crookedness or curvature, or combinations of them — might give the same general indication as eccentricity or lack of concentricity. In other words, the mechanic who turned the shaft might hunt fruitlessly for reasons why his machine, chuck or setup produced eccentricity when all the time the real trouble with the shaft was that it had become bent, bowed or oval. Machine conditions, the way a workpiece is handled (it might have been dropped), or the condition of the original cold-rolled stock all contribute to spoiling the true geometrical form of the workpiece, and in a manner different from the way eccentricity is formed.

As a matter of review, half of Fig. 3 presents diagrams of crooked, curved, tapered, oval and eccentric shafts, all of course in exaggerated form. It also shows diagrammatically the diagnosis of these several ills by means of V-block, height gage and indicator setups.

So, as a matter of definite procedure when checking concentricity, the inspector tests the shaft first for ovality. One end of the stepped shaft is rested in the V-block, as demonstrated in sketch A in the right hand side of Fig. 3, the height gage with its indicator is moved in over the shaft section as in Fig. 1 and the shaft section is revolved in the V-block to allow the indicator to register any ovality present in that section of the shaft. If an accurate measurement or reading of ovality is required, the indicator should be placed in a horizontal position (possibly by holding its base against the

vertical surface of an angle plate) and then moved up ,and down in contact with the shaft until a maximum reading is obtained. This procedure is repeated each time the shaft is rotated to a new position. The sides of the V-block shown at *A* in Fig. 3 are too high to permit this arrangement, except where the shaft extends beyond the end of the V-block. In many cases, however, a notch or hole is provided in one or both sides of the V-block so that the indicator can be used in this way. Since a sideways pressure is exerted on the shaft

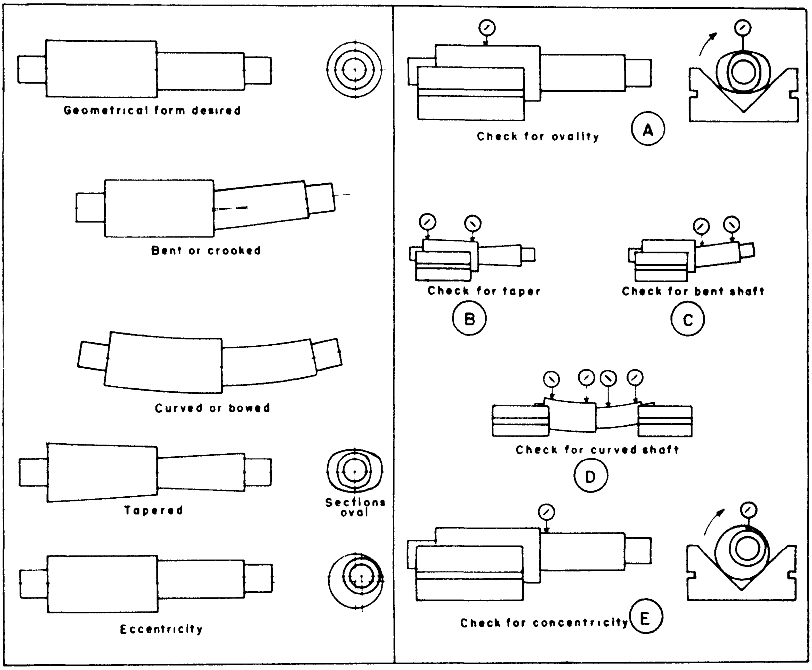


Fig. 3. Several undesirable conditions which may be present in a workpiece and methods of checking for them.

the supporting V-block should be held firmly in place on the surface plate. A record of the ovality should be made. In an exactly similar manner the opposite, the smaller section, of the shaft is rested in the V-block and its degree of out-of-round measured and recorded.

While the larger end of the shaft is still in the V-block, after the out-of-round check has been completed, the indicator is moved lengthwise along the shaft section to "explore" for

taper as diagrammed at B in Fig. 3. Similarly, after changing the shaft's position in the V-block, the smaller diameter section is checked for taper. The kind or direction of taper and its degree should be recorded. The workpiece is not, of course, revolved in the V-block when taper conditions are being explored.

One reason for observing any taper in the workpiece, especially back taper, appears when the check for a bent shaft is tried as illustrated in sketch C of Fig. 3. To determine whether or not the shaft is simply bent (in contrast to being curved) it should be indicated only at the shoulder between the two shaft sections and once again at the far end of the shaft. Do not explore in this particular operation. Probably, it is better not to revolve the shaft in the V-block in the sense in which it was turned when checking for ovality. Make the two indications on the shaft at rest in the V-block, as C of Fig. 3 shows, then turn the shaft only 90 degrees a quarter turn, and again indicate at the shoulder and shaft end. By noting the indicator readings secured at this "bent shaft" examination and comparing any increase over or discrepancy with the readings observed at the ovality and taper tests, the inspector should be able to separate any noteworthy degree of crookedness from the defects of ovality or taper.

Distinguishing One Shaft Condition from Another

The matter of separating the effects of curvature or a bowed shaft is more complex, but probably the best step is to suspend the shaft in two V-blocks as illustrated in sketch D, Fig. 3. Have each end of the shaft make contact only, say, 1/8 inch into the V-block. (Another way of checking a curved shaft is between precision centers.) The shaft is then "indicated" at several points along its periphery, preferably at locations not previously chosen for checking ovality, taper or crookedness. At each indicator position the shaft is rotated in the V-blocks. Care must be used in differentiating between these several indicator readings and the degrees of ovality, taper or crookedness previously recorded if the single element of curvature is to be diagnosed and its own value noted or recorded.

The final step is the measurement of eccentricity between one shaft section and the other. Place the larger diameter section of the shaft in the V-block and run the indicator over and onto the smaller diameter section, preferably fairly close

to the shoulder. Revolve the shaft in the V-block. If the shaft sections are not concentric, the condition will show up under the indicator if the indicator is placed close to the shoulder as sketch E in Fig. 3 suggests.

When noting the degree, in thousandths of an inch or fraction of a thousandth, of ovality, crookedness or curvature, as mentioned above, the sector of the periphery of the shaft where the condition is maximum should have been noted or marked also. And the direction of taper (front or back), if any taper appeared. The tendencies toward curvature, crookedness or ovality may tend to "subtract each other out" or

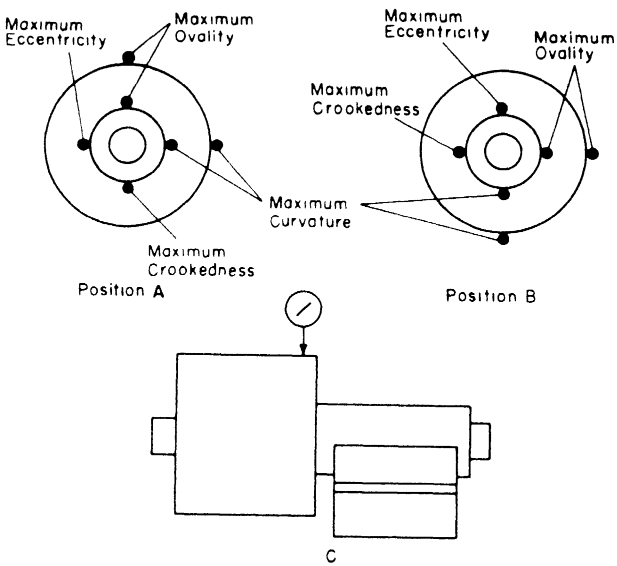


Fig. 4. Defects in a work-piece may be so located as to cancel each other out thereby giving an erroneous impression of the work-piece condition.

counteract each other, in the sense shown in Fig. 4, or one or several of the degrees of defectiveness may add themselves to the true eccentricity reading — all depending on the peripheral locations of maximum indicator readings for the several faults. If the actual shaft conditions — maximum readings — are located as diagrammed in Fig. 4, crookedness and ovality would tend to cancel each other out in their effect toward falsifying a true reading for eccentricity, as sketch A shows. Similarly, as the shaft is rotated in the V-block to position B,

during the check for concentricity, the maximum curvature indicator reading could tend to cancel or reduce the maximum eccentricity reading.

Where maximum readings for ovality, curvature or crookedness occur on the same "side" of a cylindrical workpiece as the maximum reading for eccentricity, then, as can be seen, their values should be subtracted from the reading for eccentricity in order to secure the true, so-called concentricity figure. Another double-check in effect may be made by reversing the position of the shouldered shaft in the V-block and getting an eccentricity reading as at C in Fig. 4.

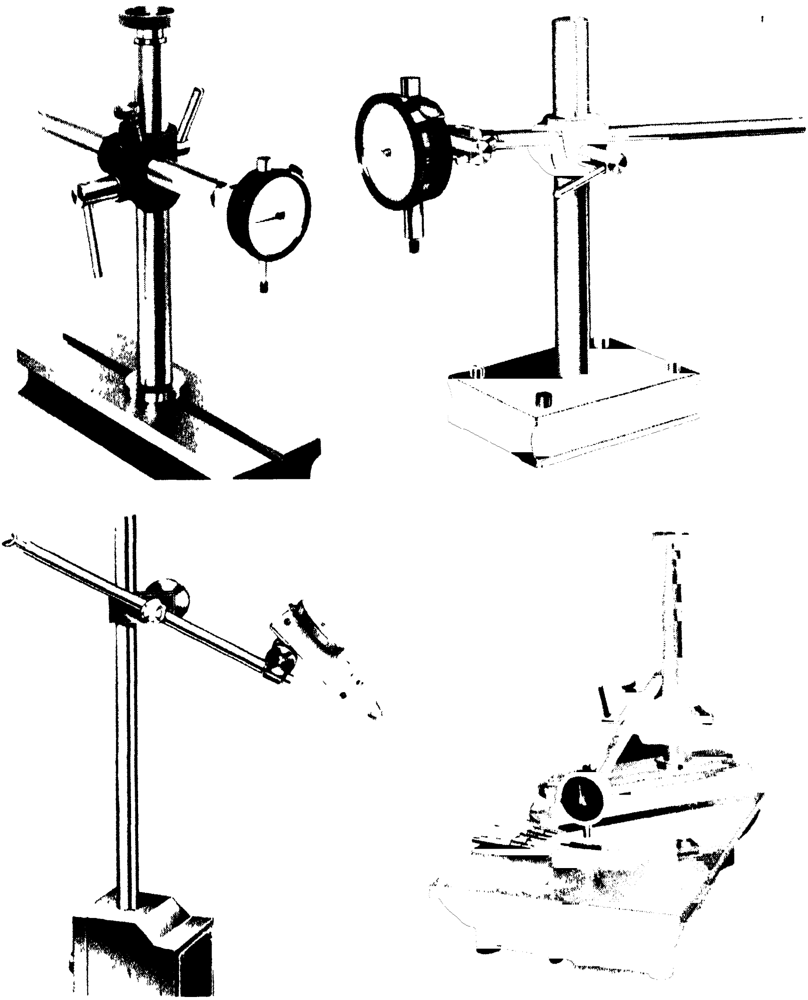
In normal, everyday, shop inspection work, however, the mixture of conditions is frequently ignored. The one reading for maximum eccentricity is made, as at E in Fig. 3 — and the shaft is rejected, if need be, on the simple count of "concentricity" not meeting specifications, because the practical effect of eccentricity, ovality, curvature and crookedness when the shaft is assembled in a hole is about the same.

The discussion concerning concentricity versus ovality, curvature, etc. has been presented in considerable detail in the hope that the new inspector will, by poring over it several times and by making some pencil sketches of his own, correctly analyze the geometry of the several situations. If a little mental preparation along this line is not taken beforehand, the inspector will probably be puzzled over what an indicator on a height gage registers when it is working on a shaft in a V-block.

The Test Set

The apparatus known in shop parlance as a "test set" is a complete instrument made up, in general, of a base, a rod-like stand, an arm and an indicator. Several varieties of test sets commercially available are shown in Fig. 5 which includes also an illustration of a test set in use. More commonly, perhaps, than height gages, test sets will be found not only in inspection areas but also in machine shop setup and control practices.

Comparing a test set with a height gage again, the general rule can be stated that test sets are not moved or slid around a surface plate. One reason is that test sets are heavier, bulkier, and cover greater surface plate area than height gages. The under side of the base of a test set is not ordinarily machined, ground and lapped to the precise flatness of the



Courtesy of Brown & Sharpe Mfg. Co
Courtesy of Federal Products Corp.

Fig. 5. Commercial test sets.

similar height gage foot block surface. An inspector should not attempt to use a test set like the more mobile height gage unless he has made certain that the test set base has unusually good characteristics in regard to flatness, warp or level, and smoothness. The height gage may be used, and is used, consistently as a test set, but there are few situations where a test set may be used literally as a height gage.

The upright post in a commercial test set may not be truly vertical, square, to the base. Any good height gage should withstand a squareness test. The uselessness of attempting too much precision in making a test set appears in the illustrations in Fig. 5; not only is there a clamp device that will move up and down the post, that can be turned and twisted to any angle, but this clamp holds an arm that can be extended or retracted, elevated or lowered, turned or twisted to almost any conceivable angle or location in space.

No, the test set is not moved; it is set up where required and the work is brought *to* the test set. In fact, one model of test set, see Fig. 5, has a so-called magnetic base to anchor it firmly to the surface plate or to a machine bed. A test set offers no graduated, calibrated scale with a vernier, in the sense of the height gage's beam; its measurement is made with an indicator.

Because a test set is purposely made either with a heavy base, a magnetic base or with a base that can be readily clamped down, it is perhaps more useful, more reliable and more accurate for measuring diameters, heights, offsets and shoulders than a height gage, which is prone to tip or cant a little unless held firmly by one hand. A test set has, too, a "production" value in that it is frequently the instrument selected when a succession or a large quantity of similar pieces is to be inspected. Once set up, the test set allows the inspector the use of both hands for manipulating the pieces to be measured, as Fig. 5 illustrates.

Using the Test Set Correctly

In addition to the sort of routine apparatus maintenance and examination already discussed many times thus far in this book, one or two precautions relating particularly to the test set should be mentioned. As a test set is being set up, be sure all clamps are tight. Be sure it sets firmly, without any tendency to wobble or rock, on the surface plate — clamp it down if necessary.

Make every reasonable effort with a test set to have the extension arm as low down toward the base on the upright post as possible. Then try not to let the extension arm holding the indicator extend, overhang, any further than necessary beyond the base and the clamp holding it to the upright post. Where the extension arm holding the indicator is high up

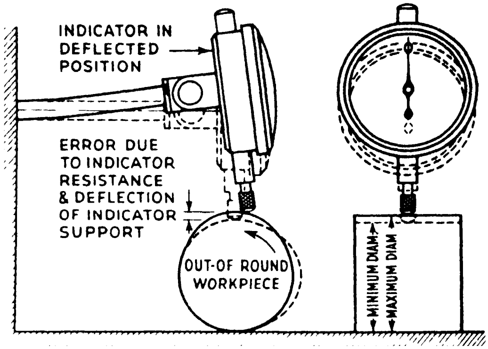


Fig. 6. Measurement errors caused by the deflection of the indicator support arm in a test set.

near the top of the post and/or where it is out well toward the limit of its length beyond its clamp and the base, both a powerful leverage and a cantilever effect are obtained which will produce measurement errors. Under such setup conditions, the base will invariably tilt a trifle, heavy as it is, or, if the base is clamped down or magnetic, the upright post and especially the extension arm will bend or deflect a little. At all odds, the effect to be avoided is illustrated in Fig. 6.

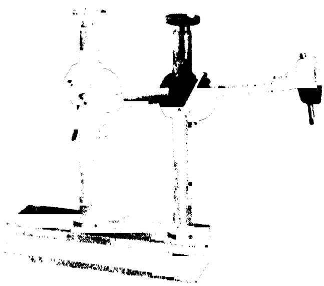


Fig. 7. Test set equipped with extra supporting post to minimize deflection errors.

The sort of test set difficulty just described can be ingeniously offset almost completely by using the model of test set supplied with a channel iron base and by using an extra post with an extra clamp. The extension arm is threaded through the pair of clamps, as in Fig. 7, and gains the extra support, steadiness and stability of the parallel upright posts.

A thousand excellent examples of parts or pieces might be selected to illustrate surface plate practice and the use of test sets and other indicating equipment in modern industrial inspection and gaging methods. To choose just one example which would supply the answer to every surface plate problem any new inspector anywhere might come up against is, of course, impossible.

Inspection of an Automobile Engine Piston

Realizing this, we have chosen to talk about the inspection of a piston like that pictured in Fig. 8, having in mind that even the most amateur mechanic doubtless has some concep-

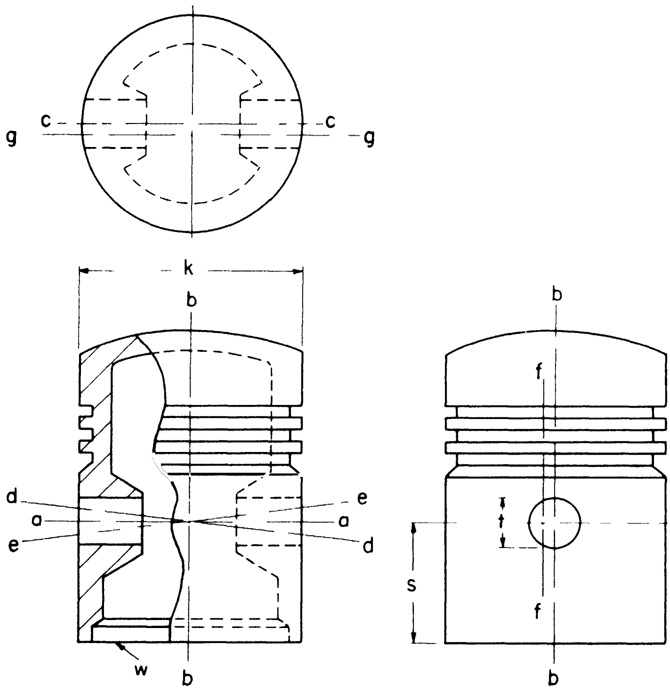


Fig. 8. Automotive-type piston showing some of the dimensions that are to be checked.

tion of an automobile engine piston. Pistons are used, of course, in aircraft engines and diesel locomotives, in motorcycles and outboard motors. Pistons of this general type appear in tiny compressors which keep your refrigerator cold. The choice of an ordinary piston for this example does offer

a fair variety of tolerances and precisions and a reasonable choice of ordinary surface plate techniques.

The use of the surface plate and other measuring tools and apparatus has already been described, in text and illustrations used thus far, and surface plate techniques will appear casually, at least, in the discussions to come on special measuring problems. Out of it all, it is to be hoped that the new inspector will get enough of the basic principles and geometry involved

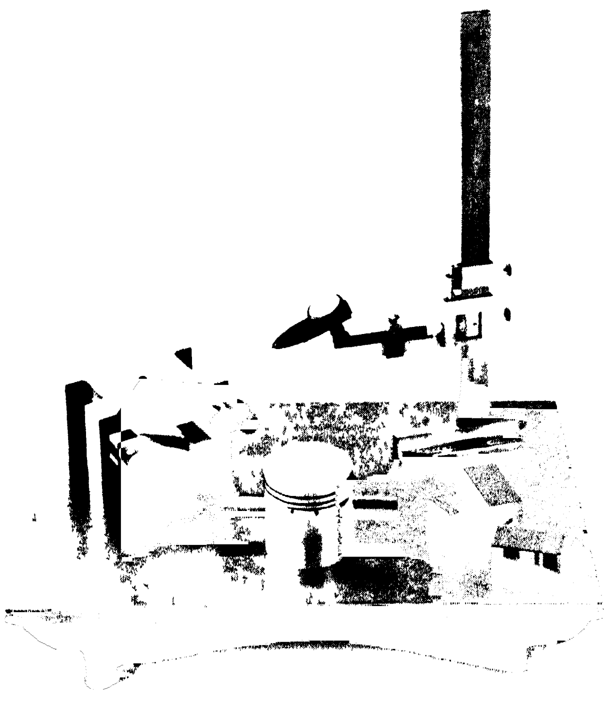


Fig. 9. Some of the surface plate apparatus that is used to check the piston of Fig. 8.

to take the raw edges off, at least. The rest will have to come from practice, experience, observation and the use of native mechanical ability, wherever he works at inspection and uses a surface plate in a factory.

Figure 9 shows not only the piston in question but also a collection of surface-plate apparatus to be used to check the dimensions on the sketch in Fig. 8. This sketch does not, pur-

posely, show all the dimensions to be checked — all of the dimensions appearing on the original blue print — but enough typical measurements have been selected to illustrate the general procedure of surface-plate work. Also, any experienced inspector can quite properly disagree with the general order of taking the measurements as suggested below and even with some of the particular methods or instrumentation about to be described. Perhaps more than in any other general system of measurement, surface-plate practices reflect personal preferences.

Checking for Squareness of End and Measuring Outside Diameter

So then, the first step in checking the conformance of the sample piston to specifications would be to rest it in a V-block and check the squareness of the machining of end surface *w*

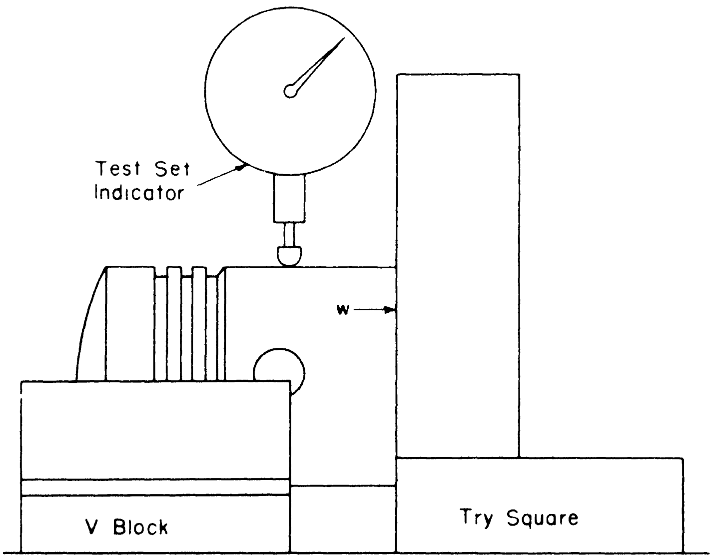


Fig. 10. Checking for squareness of end and ovality of the outside diameter of the piston shown in Fig. 8.

with the axis of the piston. Since this element is not too critical, it can be checked with a try square as illustrated in Fig. 10, turning the piston, once, 90 degrees in the V-block.

Almost simultaneously the test-set indicator can be set over the piston and its ovality or out-of-round can be checked as

Fig. 10 also indicates diagrammatically. Since several of the blue print tolerances for some of the piston-ring groove and skirt diameters are in the neighborhood of .001 inch, any out-of-round should not exceed .0005 inch.

Remember the operation above does not measure the diameter itself. Remove the V-block and locate the piston, on its side, directly under the test-set indicator to make the O.D. (outside diameter) checks.

For this purpose make up a gage-block stack the exact equivalent of the blue print specification for diameter k, Fig. 8, and set the test-set indicator to its 0 by manipulating the

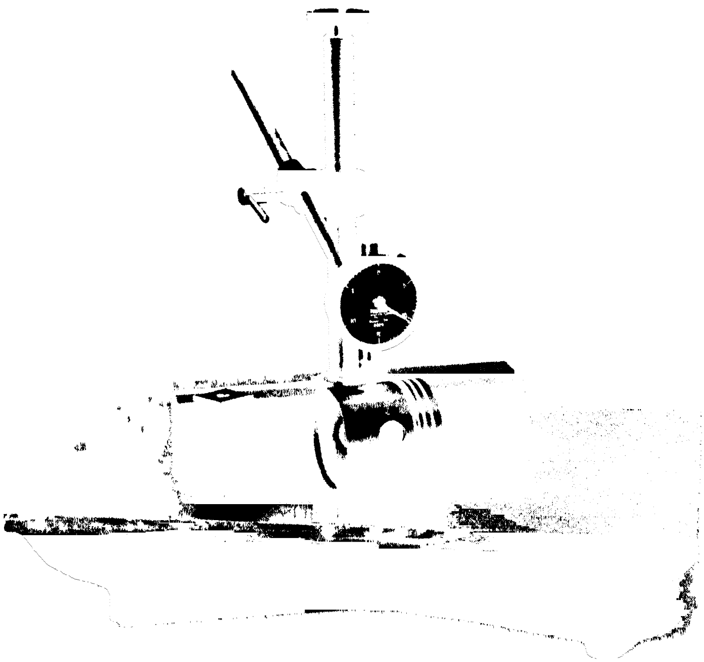


Fig. 11. Measuring the outside diameter of the piston shown in Fig. 8.

clamps, post and arm of the test set and turning the indicator dial. Then slide the gage-block stack away from the test set and roll diameter k of the piston under the indicator point, as in Fig. 11.

If the sample piston diameter is less than the specified diameter, as represented by the gage block stack "master," it

will show in tenths or thousandths as a minus reading on the indicator. Similarly, an oversize piston diameter will appear as a plus indicator reading.

Of course O.D.'s like *k* of Fig. 8 could be checked with micrometers or vernier calipers but the method above was offered to illustrate one surface-plate technique and also to lead up to the use of "comparators," a type of instrumentation to be described farther on.

Checking Direction of Wrist-pin Hole Axis

The location of the wrist-pin hole, dimension *s* in Fig. 8, is also important but, before the actual measurement is taken, conditions like those shown by lines *d-d, e-e, f-f,* and *g-g* must be checked. Or, shall we say, the geometrical position of the hole in relation to the piston axis — whether it slants up or down, whether it's twisted, whether it's off center — is more

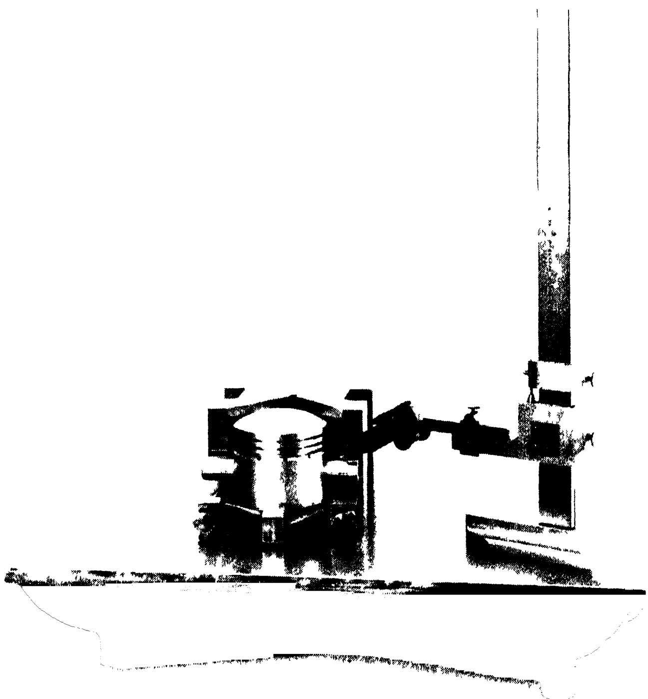


Fig. 12. Checking to determine whether or not the wrist-pin bearing holes are perpendicular to the axis of the piston.

important to the correct operation of the piston in the cylinder, perhaps, than the actual location of the hole, dimension *s*, in relation to the bottom of the piston skirt, surface *w* in Fig. 8.

The wrist-pin holes should have been bored on the center line *a-a*, at 90 degrees to the axis, *b-b*, of the piston. The bore should not slant as lines *d-d* or *e-e* suggest, Fig. 8. Such a relationship can be verified by first plugging the wrist-pin holes. In this case, a long plug should be selected — long enough to go through both wrist-pin holes and overhang a little on each side. Its diameter should be so carefully dressed that virtually a wringing fit is secured. The blueprint allows a tolerance of only .0001 inch for diameter *t* of the wrist-pin holes, Fig. 8. For this reason, plugging these holes with tapered parallels or selected plug gages will not be accurate enough. A through plug with the suitable lapped diameter is the answer.

Next clamp the plugged piston upright in a vertical V-block setup as illustrated in Fig. 12. Using the height gage with a test indicator, move the point of the indicator over the top of the plug projecting out of one side of the piston as shown in Fig. 12 and also diagrammatically at *n* in Fig. 13.

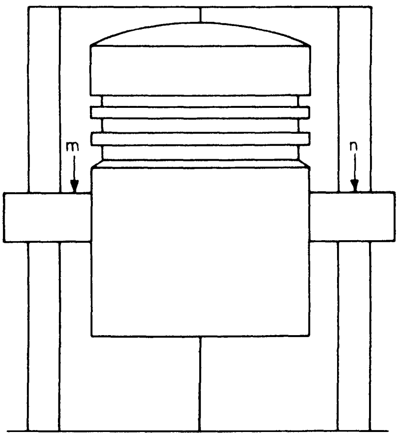


Fig. 13. Diagram showing the points at which measurements are taken when using the set-up of Fig. 12.

The particular technique involves loosening the height gage slider and moving it up and down until the test-indicator point just touches the top of the plug in the wrist-pin holes. As the indicator point touches, the indicator hand will move or

register. Clamp the height-gage arm and slider tight. Move the height gage back and forth so that the test-indicator point rides up to the high point of the plug periphery. The indicator reading should be taken at position *a*, Fig. 14, and not at *b* or *c*. Position *a* can be accurately determined by moving the indicator point back and forth — literally by sliding the whole height gage back and forth — and as the indicator point progresses from, say, position *b* in Fig. 14 to position *c* the indi-

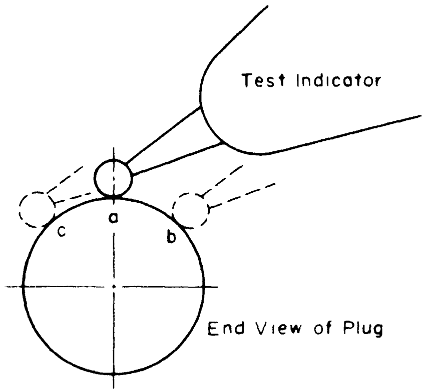


Fig. 14. When indicating over a plug as shown in Fig. 12, the reading at the high point, position *a*, should be taken, not that at position *b* or *c*.

cator hand will move in one direction around the indicator dial to a "high point" and then start to recede or reverse. With the pointer at this high point, the indicator point is at *a*, Fig. 14. Having located the height gage and indicator so that the indicator point is at *a*, set the indicator to its 0 by using the height gage fine adjustment or by turning the indicator dial to 0. Many inspectors do not bother with "zeroing" the indicator; they simply note or record the actual indicator dial reading at the high point. However, memory is slippery and there is always the chance either of misreading the indicator dial or making an arithmetical miscalculation.

Slide the height gage around and over to position *m*, Fig. 13, in other words to the other end of the plug locating the wrist-pin hole. Again, move indicator and height gage back and forth as previously directed until it comes to rest on the high reading (until it rests on the true vertical diameter of the plug). This time, however, do not touch the height gage

fine adjustment nor the indicator dial. Gain the high point for *m* simply by locating the height gage on the surface plate so that a maximum indicator reading is obtained.

The indicator reading at *n*, Fig. 13, was set at 0. The other indicator reading, in "tenths" or thousandths, at point *m*, then, tells how much the center line of the wrist-pin holes tips up or down. If the wrist-pin hole center line is not parallel to the surface plate, it is not perpendicular to the vertical axis of the piston. In other words, the wrist-pin bores slant like *d-d* or *e-e* in Fig. 8. If the test indicator reading at *m*, Fig. 13, is the same as at *n*, (or within, say, .00005 inch) the wrist-pin bores can be considered on the true center line *a-a*, Fig. 8.

The possibility of noting a high point indicator reading at position *n* rather than setting the indicator to 0, was mentioned. It can be seen now that there is more likelihood of error in getting the difference between readings *m* and *n*, if the 0 setting of the indicator is not used.

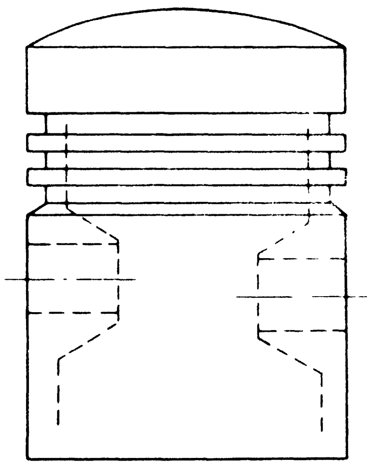


Fig. 15. Possible misaligned condition of wrist-pin bearing holes; misalignment shown exaggerated.

Checking for Stepped or Offset Wrist-pin Holes

If, for some reason, the wrist-pin bores are perpendicular to the piston axis but are "stepped" or not on the same centerline, as exaggerated in Fig. 15, another, though similar, type of test is needed. In the first place, if the two bores are stepped, the longer through-plug probably cannot be forced through

both holes. In the second place, to analyze a stepped condition as illustrated in Fig. 15 in contrast to the slanting bores of *d-d* and *e-e* of Fig. 8, each wrist-pin hole must be plugged with its own separate, shorter plug. Then the height-gage indicator test is made as in Fig. 13.

Once more, referring to Fig. 8, we need for obvious reasons to be sure that the wrist-pin holes have not been offset — bored off center — as lines *g-g* or *f-f* would suggest — that the axes of the wrist pin holes are on the true diameter of the piston itself.

This time, the plugged piston is rested on a horizontal V-block as diagrammed in Fig. 16. With the height gage indi-

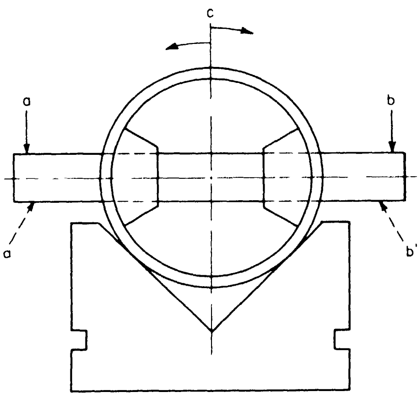


Fig. 16. Checking to determine whether or not the center line of the wrist-pin bearing holes and the center line of the piston coincide.

cator at points *a* and *b*, rotate the piston a trifle in the V-block, as indicated at *c*, until the indicator reading at *a* corresponds to the reading at *b*. By this means, the plug is made truly horizontal and parallel to the surface plate. Now turn the plugged piston completely end over end in the V-block, opposite side up in other words, so that points *a′* and *b′* on the plug come up under the height gage indicator. Again slightly revolve the piston as at *c* until the plug is level and indicator readings *a′* and *b′* are alike.

If readings *a′* and *b′*, which are in themselves alike, differ from the previous readings *a* and *b*, then the plug center-line is not concentric with the piston center-line. It is offset by one-half the number of tenths or thousandths difference between the pairs of readings.

The same general technique is used where slots are milled in shafts. Is the slot on the center line where it belongs as at A in Fig. 17 or is it at one side as at B? By plugging the slot with a flat strip of metal and using a V-block as at C, the true location of the slot can be determined. "Level off" the flat metal plug and note the final, level indicator reading. Reverse the shaft and slot as shown at D, level off again, and compare

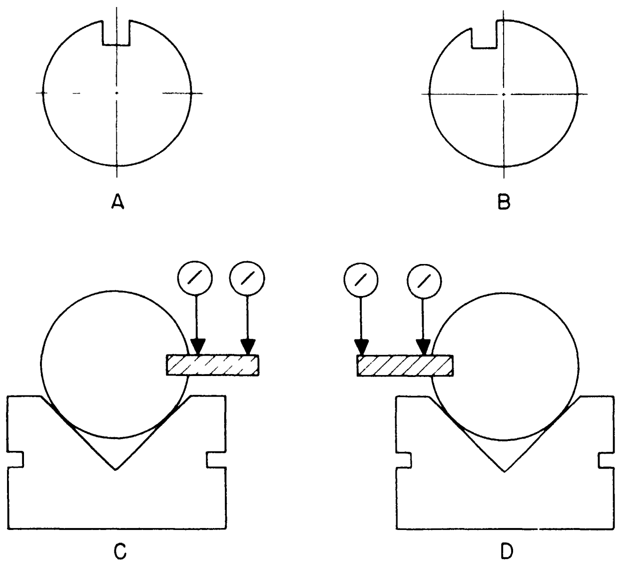


Fig. 17. Checking to determine whether or not the center line of the milled slot is radial. (A) Correct alignment. (B) Incorrect alignment.

the latter final reading with the indicator reading at position C. (Before using the plug, be sure that the two surfaces which the indicator is to contact are parallel with each other.) One-half of the difference, if any, is the amount the slot is located to one side of the true geometric shaft center.

Measuring Vertical Location of Wrist-pin Holes

Returning to the piston measurements, Fig. 8, we are now in better position to measure the vertical location of the wrist-pin holes, dimension *s* in Fig. 18, because we are aware of any possible slanted, stepped, offset or non-concentric conditions.

Ordinarily the tolerance allowance for a dimension like *s* in Fig. 18 is of the nature of .002 inch or greater. Hence,

dimension s could be secured accurately enough with the solid height gage measuring arm (using the scriber point and not the indicator) and reading the dimension by the graduations on the height gage beam. (Of course, the hole is first plugged and measurement s' over the top of the plug is taken. One-half the diameter of the plug is then subtracted from s' to obtain s.) Similarly, dimensions i, j and h of Fig. 18 could be taken directly with the height gage.

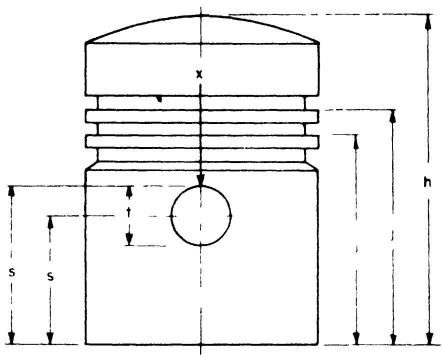


Fig. 18. Dimensions s' and t are measured and used to calculate dimension s.

But suppose the blue print gave a closer tolerance (.001 inch or less) for dimension s, Fig. 18. In that event, a test indicator would be clamped on the height gage which would be set to its 0 over a gage block stack equal to dimension s', Fig. 18. Dimension s' is of course the sum of the blue print specification for s plus ½ of t. Whatever the indicator reads, plus or minus at x, Fig. 19, would then be the amount the actual dimension s of the sample piston varies from the blue print requirement.

Efficient Way to Use Gage Block Master

Any of the exercises described above suggesting the use of a height gage, indicator and gage block stack bring up another little professional touch the beginner can adopt, especially where accurate measurements to .0001 inch or even .00005 inch are required.

The general tendency is to stand the gage block stack on the surface plate at one location and the workpiece in another location. The height gage occupies a third location. This rela-

tionship is illustrated diagrammatically at A in Fig. 19. The height gage is then slid over path *a* and the indicator is zeroed over the gage-block stack master. The height gage is then moved in a path somewhat like *b*, until the indicator registers for the measurement on the workpiece.

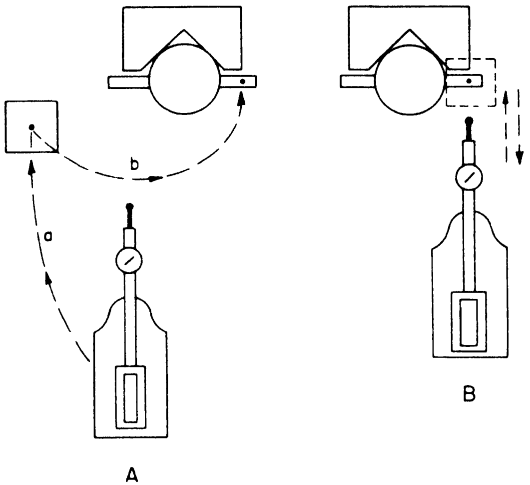


Fig. 19. (A) Possible positions of work-piece, gage block stack and height gage. (B) For more accurate measurements, gage block should be placed close to the work as shown so that height gage movements are short.

Now remember the measurement is wanted to an accuracy of .0001 inch or .00005 inch. Also remember the face of a surface plate is not guaranteed to be utterly free from warp or waviness — at best a tolerance of at least .0002 inch must be considered for surface unevenness or surface plate irregularities. There is always the possibility of dirt, chips, scratches and burrs on the plate, instruments and accessories any of which can introduce an error of .0002 inch or more.

To reduce the chance of error to a minimum it is suggested that a height gage be moved always in as narrow, restricted and short a path as possible. It should be slid back and forth over the *same* path if possible. This is one situation where "staying in a rut" pays off.

The professional way is illustrated at B in Fig. 19. The gage-block stack and height gage are located close to each other. The height gage is "mastered" on the gage blocks. The gage-block stack is then moved away and the workpiece is

placed on the spot occupied by the gage blocks. As shown at B in Fig. 19, the original gage block stack position appears in dotted lines. Where this technique is followed, the height gage can be moved back and forth, perhaps only a fraction of an inch, and always in the same straight narrow path, as the arrows at B in Fig. 19 suggest.

Where the accuracy of the surface plate is questionable, and where extra close measurements are needed, the especially accurate machinist's flat is frequently used. In the example shown in Fig. 19 it would be entirely possible to place a flat on the surface plate and locate the gage block stack and then the workpiece on the flat. Furthermore, the height gage could be stood on another, adjacent machinist's flat.

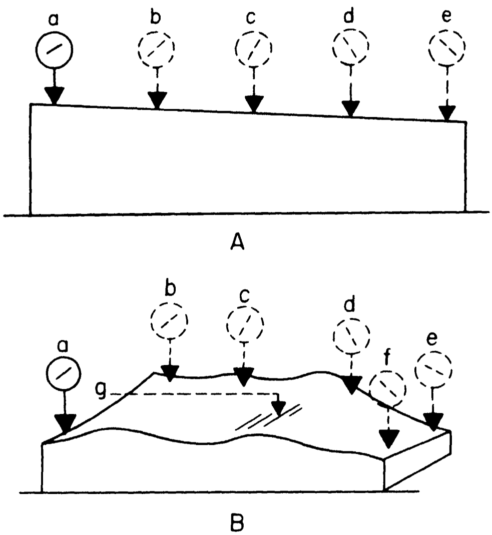


Fig. 20. Methods of exploring the contour of a work-piece. (A) Tapered work-piece. (B) Work-piece of irregular shape.

Exploring with Height Gage and Test Indicator

The idea of "exploring" with a height gage and test indicator has been mentioned. If, somehow, a short motion picture could be readily introduced into the reading of a book, the description of exploring would need few words.

If it is a matter of simple taper or lack of parallelism on a simple oblong, flat or cylindrical piece, the conception of exploring can be shown geometrically as at A in Fig. 20. The

workpiece can be laid on a surface plate and the height gage moved along its upper surface as at *a, b, c, d* and *e*. If the piece is cylindrical, it can be located in a V-block for the same sort of test.

In exploring with an indicator, however, the principle of the reference point comes into use. In Fig. 20-A, for instance, the height gage indicator might best be zeroed at position *a* (or at position *e*). As the height gage and indicator are trailed along the piece the indicator will register the changes in height as it moves from *a* to *e* (or *e* to *a*) through *b, c* and *d*. Usually, the mechanic will zero at *a*, say, and then take the reading at *e* without bothering with readings *b, c* and *d*. But one position must be the reference point, else exploring will not mean much.

Surface irregularities, waviness, hollows, humps, warp, any lack of parallelism or flatness on flat stock can be explored, for example, with an indicator-equipped height gage. An attempt has been made to sketch this conception at B in Fig. 20. Here it would be better probably to zero the indicator at position *a* as a reference point. Then the degree of waviness or warp, either plus or minus as compared to *a*, can be determined by checking at various locations such as *b, c, d, e* or *f*, or even to an extent into the general area of the workpiece as at *g*.

Checking Inside Diameters with Test Set

The surface plate techniques described thus far have at least implied measurements and comparisons made on outside diameters, cylindrical workpieces or flat work. Many of the suggestions apply also to inside diameters. Figure 21 shows a set-up for checking an inside diameter.

Under the conditions shown in Fig. 21, a tapered or bell-mouthed situation in the bored hole could be explored with the height gage, but one or two sharp warnings are in order. Where large-diameter bores are involved, such as are pictured in Fig. 21, it is difficult, many times, to plug them for the purpose of securing coordinates or center locations. The coordinates can be secured by taking measurements at the circumferences, as Fig. 21 intimates, but several precautions, based on obvious, common-sense geometry, must be rigidly observed.

In the first place, what might be called the axis of the height gage and indicator should be strictly parallel with the axis

of the hole or bore. The indicator should approach the circumference, as shown in position *e*, Fig. 22, and not at an angle as suggested by the dotted line d-d. The height gage is then moved slowly from right to left a trifle — motions strictly perpendicular to the hole axis suggested by the arrows at *f*

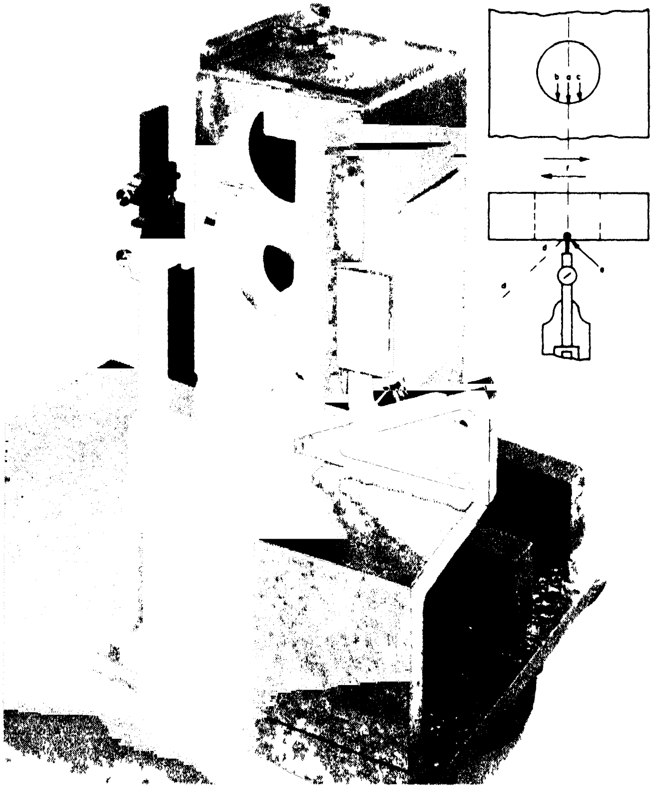


Fig. 21. Surface plate set-up for checking an inside diameter. Fig. 22 (Insert) Technique employed in locating point on the true vertical diameter of a hole.

in Fig. 22 — from positions *b* to *c*. The point where the test indicator hand reaches a static position, hesitates, and starts in the reverse direction is location *a*, very close to being on the true vertical diameter of the hole.

Where hole locations must be checked for blue-print tolerances finer than .0005 inch, the above method very probably should be discarded in favor of somehow plugging the hole.

Mechanical Principle of the Dial Indicator

Thus far, test indicators and dial indicators have been mentioned as if the new inspector had full-grown acquaintance with them. The indicator is, however, a special measuring tool in itself. It represents another basic method of securing measurement in contrast to the linear system of the steel rule and vernier equipment, the 40-threads-to-the-inch lead of a micrometer screw or the building-block idea of gage blocks. An indicator has many attributes, but also peculiarities and some shortcomings all its own. Even experienced mechanics may forget or ignore some of the intrinsic values and shortcomings in dial indicators as measuring instruments.

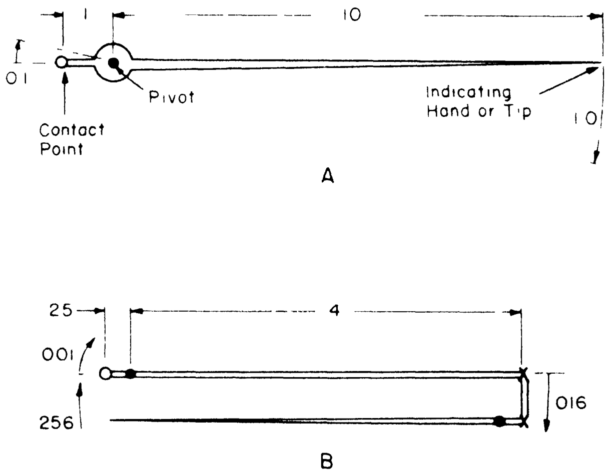


Fig. 23. Schematic diagrams of elementary lever mechanisms used in some commercial test indicators: (A) Simple lever having 10:1 ratio; (B) Compound lever having 256:1 ratio.

One basic mechanical principle of the dial indicator can be quickly understood by considering the geometry of the elementary mechanism appearing in diagram A of Fig. 23 illustrating a 10-to-1 lever. It is obvious that the tip of the indicating hand will move ten times as far (and ten times as fast, incidentally) as the contact point. Some commercial test indicators use directly this principle of the ratio of lengths either side of a pivot.

If the distance from contact to pivot, Fig. 23-A were ¼ inch, for instance, and the length of the pointer beyond the pivot

were 4 inches — a 16 to 1 ratio — then a .001-inch movement of the contact point would be reflected as a readily distinguishable movement of .016 inch on a dial, say, of the tip of the pointer or hand. The leverage could be compounded, perhaps as sketch B in Fig. 23 suggests, so that, in this case, an original contact point movement of .001 inch is "blown up" or amplified to .256 inch or, practically, $\frac{1}{4}$ inch on a dial. Or .0001 inch can be amplified to .0256 inch.

Amplification versus Magnification

Incidentally, as an interesting aside, this idea of one part of a me hanism moving faster than another part, the concept of enlarging a motion or movement, brings up the gaging and inspection jargon of "amplification" and "magnification" and, if instrumentation is to be studied, the definition of one term as distinguished from the other should be made, perhaps reasonably clear. In the case of the lever-pivot mechanism the measurement is amplified. If on the other hand the graduations on an instrument are viewed through a magnifying glass, the measurement is considered magnified. A dial indicator amplifies a measurement through a gear train (as will be seen) ; the same measurement is then amplified by the pointer or hand and the dial divisions and could be further magnified through a glass. Optical projectors magnify measurements without amplifying them whereas, as will be seen in a section farther on, amplification is accomplished through the transformers and tubes of an electronic system. The reason for mentioning what may seem to be an academic difference is to point out that instrument error may occur from or through the mechanics of amplification or from the visual error of reading a magnified scale, and sometimes it is necessary to analyze the cause of errors. In the shop, the terms are used more or less interchangeably to express the idea of "blowing up" a dimension to readable proportions.

Understanding the Dial Indicator Mechanism

Commercial dial indicators use a gear train to secure amplification. When one gear meshes with another, see Fig. 25, the angular amount the driven gear turns depends not only on the amount the driving gear turns but also on the ratio between the number of driving gear teeth and the number of driven gear teeth. Since the teeth on meshing gears must have

the same spacing or pitch, this ratio can also be reduced to terms of pitch diameters of the two gears.

In diagram A of Fig. 24 the driving gear *a* is considered as having 100 teeth and the driven gear, *b*, as having 10 teeth. If gear *a* rotates once, then gear *b* will be turned through 10 revolutions.

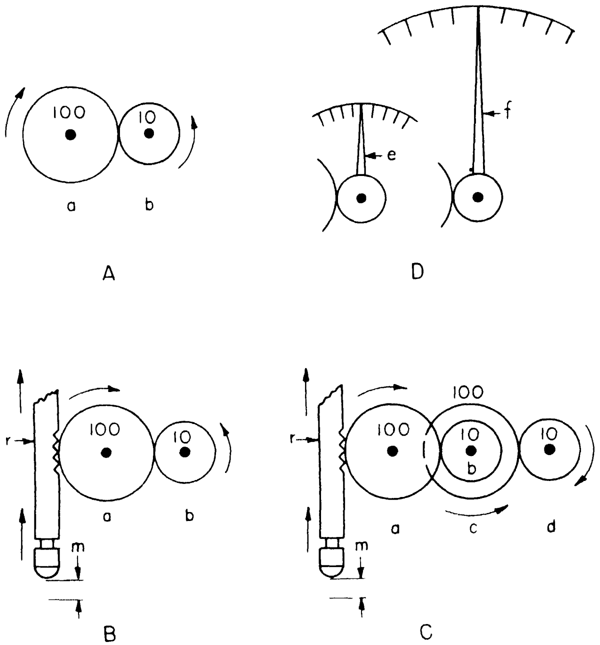
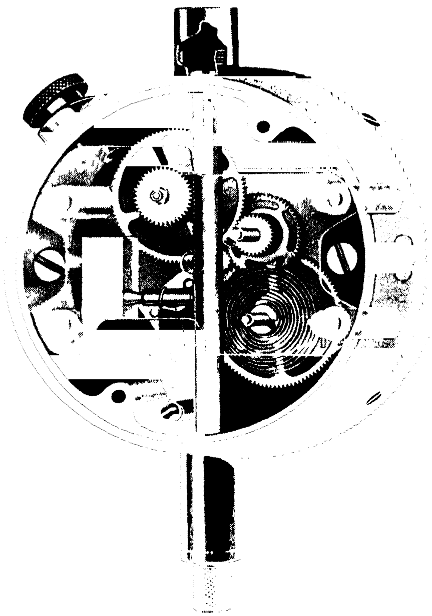


Fig. 24. Schematic diagrams of dial indicator amplifying mechanisms; (A) Simple gear train, 10:1 ratio; (B) Simple gear train combined with rack, 10:1 ratio; (C) Compound gear train and rack, 100:1 ratio; (D) Indicator hand *f* is twice the length of hand *e* therefore doubling the amplification.

The commercial dial indicator mechanism makes use of this principle by transferring a linear difference in space to a gear train through a rack gear. Sketch B of Fig. 24 shows the motion *m* of the rack *r*. A point on the circumference of gear *a* consequently moves as far as the linear movement, *m*, of the rack *r* and, because of the gear ratio, a point on the circumference of gear *b* moves through ten times the angle that a point on gear *a* moves.

Greater amplification can be obtained by increasing the diameter of gear *a*, but it is usually secured, for the sake of

compactness in a dial indicator, by "compounding" a gear train as suggested in diagram C of Fig. 24. Here, another gear, *c*, is fastened on the shaft of gear *b*. If gear *c* is fastened to the same shaft as gear *b*, any point on its circumference moves through the same angle as a point on the circumference of gear *b* or through 10 times the angle of a point on the circumference of gear *a*. Then, with the ratio of the number of



Courtesy of Federal Products Corp

Fig. 25. Cutaway view showing the construction of one type of commercial dial indicator.

teeth on gear *c* to the number of teeth on gear *d* equal to 10 to 1, any point on the circumference of gear *d* will move through 10 times the angle of a point on the circumference of gear *c*, or 100 times the angle of a point on the circumference of gear *a*. Thus, an amplification of 100 times is obtained.

In addition to securing amplification of movement through gear ratios, the dial indicator translates the motion of the circumference of gear *d* through a pointer or "hand" swinging over a graduated dial as diagrammed at *e* in sketch D of Fig. 24.

Such a motion can be further amplified by increasing the length of the hand as at *f*. Where the hand, *f*, is twice as long as the hand at *e*, the dial graduations for *f* can be twice as far apart and the reading of a measurement consequently made that much more discernible to the eye.

The principles of amplification and magnification secured through dial indicators have been discussed in some detail in order to emphasize, farther on, certain inaccuracies and shortcomings potential in the dial indicator as a shop measuring tool and the common precautions necessary in using one.

Construction of the Dial Indicator

First, however, the actual construction of the everyday commercial dial indicator should be explored and Fig. 25 is supplied to illustrate it photographically. A little study of Fig. 25 will show that an indicator consists primarily of a metal case (usually brass) which acts, mechanically, as a rigid frame or foundation for the instrument mechanism, as a protective covering, and also as a means for handling it. Anyone who is a stranger to dial indicators would probably think in terms of clocks or watches the first time he saw one.

This frame, or the case, supports a gear train, the gear rack and its bearings, the graduated dial and a protective crystal held in a bezel. As in the case of the micrometer, the inspector should have a ready acquaintance with the common names of the various parts and features of an indicator and Fig. 26 has been provided for that purpose.*

A dial indicator is not an independent measuring device in the sense that the steel rule or the micrometer or the gage block is. The dial indicator must be clamped to, mounted on or fastened into supplementary equipment. In this respect, it might be compared to the vernier height gage which, by deliberate design, is useless in itself as a measuring instrument but must have a surface plate or the equivalent to complement or complete it. In other words, a dial indicator provides a mov-

* The inspector should obtain from The Superintendent of Documents, U. S. Government Printing Office, Washington, D. C. a copy of the U. S. Department of Commerce, National Bureau of Standards bulletin CS(E)119-45, the commercial standard on dial indicators for linear measurement. This booklet outlines the agreements reached by a committee on American Gage Design (AGD) in connection with, among other things, standard nomenclature for dial indicator parts and certain standard dimensions and specifications on indicators.

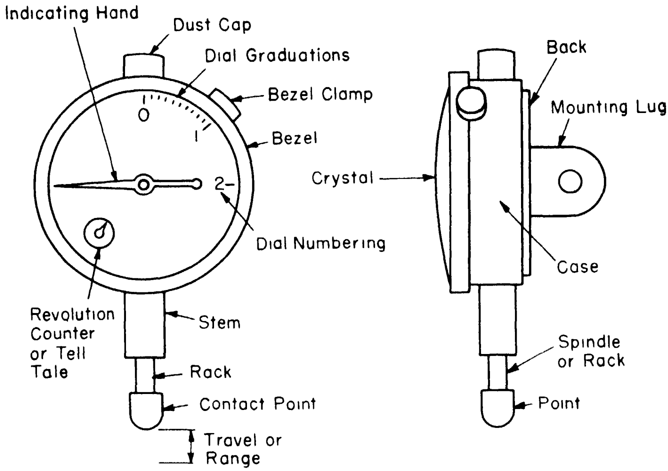
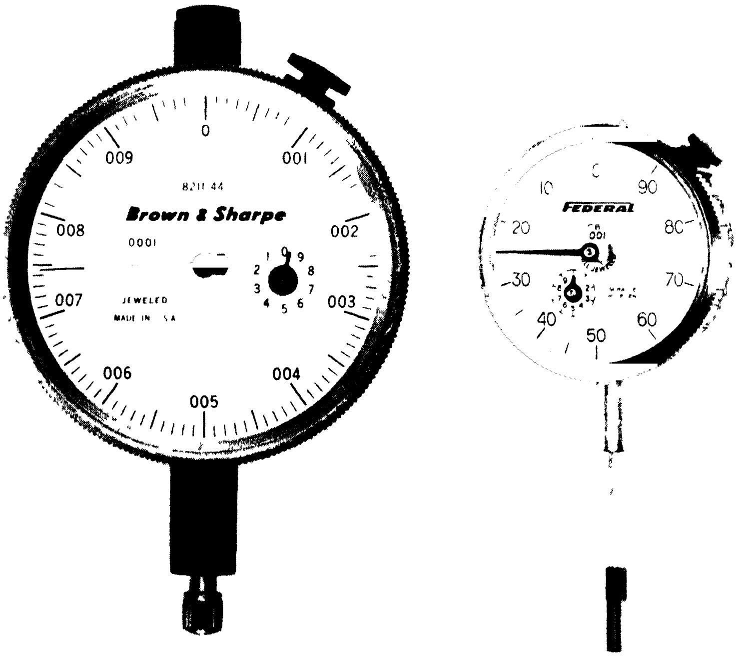


Fig. 26. Nomenclature used in describing dial indicator components.



Courtesy of Brown & Sharpe Mfg Co *Courtesy of Federal Products Corp*

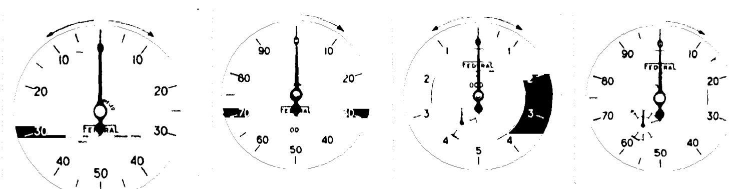
Fig. 27. Long range dial indicators equipped with revolution counters. Tenths of an inch or ten-thousandths are read on the revolution counter, thousandths of an inch or "tenths" are read directly on the main dial.

able or measuring anvil, surface or contact but not the fixed, the reference surface. Thus, it is apparent from previous descriptions and illustrations that dial indicator measurements are secured through the movement or deflection of the indicator point and the travel of the spindle or rack that is, in turn, transmitted and amplified through a gear train and indicating hand which moves around a graduated dial.

The standard (AGD) indicator is assembled so that the hand is in the so-called "9 o'clock" position (see Fig. 26) when the spindle is at rest. AGD standards also require the standard travel or range of the indicator spindle to be such that the hand will make 2½ revolutions at least from the original 9 o'clock position. Indicators are available, of course, with a range less than 2½ turns, and as many more where the hand turns through ten revolutions (in some very special designs even more). Long range indicators, so-called, are usually equipped with small revolution counters or tell-tales, see Figs. 26 and 27.

Balanced Dials Versus Continuous Dials

Indicators come with what is known as balanced dials and continuous dials — with and without revolution counters — as illustrated in Fig. 28. The reasons for using balanced dials



BALANCED DIAL — CONTINUOUS DIALS — BALANCED DIAL and REVOLUTION COUNTER — CONTINUOUS DIAL and REVOLUTION COUNTER

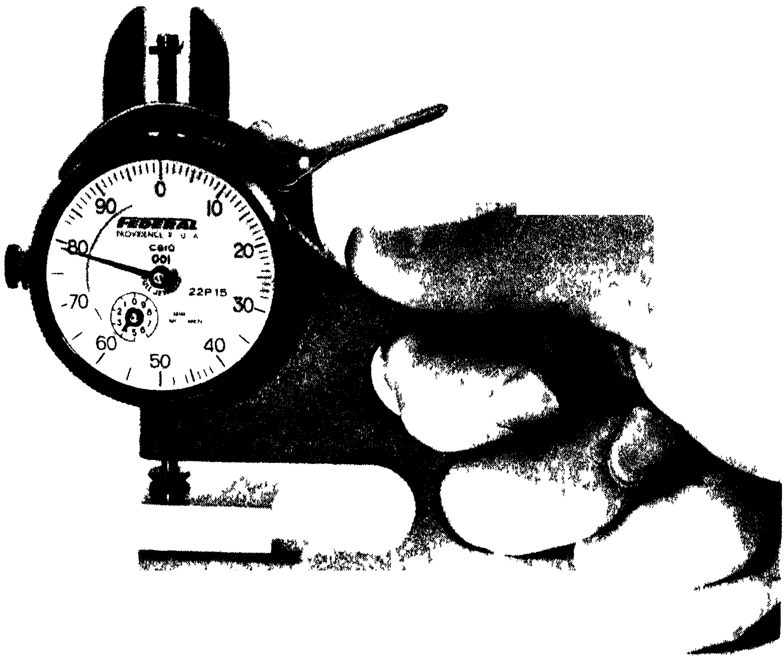
Courtesy of Federal Products Corp

Fig. 28. Various types of dial faces used on dial indicators.

versus continuous dials will become more apparent as gages and comparators are studied in the sections farther on, but, as a quick explanation, it might be said that if the tolerances are bilateral, as ± .001, the balanced dial indicator is preferable, and if they are unilateral, as –.000″, + .002″, the continuous dial type would be preferred.

The use of the revolution counter on the continuous dial indicator is rather obvious. One complete revolution of the big

hand on the continuous dial indicator in Fig. 28 registers .100 inch. If, however, the measurement makes the big hand turn rapidly through two or three revolutions, the tell tale or revolution counter is necessary. The indicator in Fig. 29, for example, registers .379 inch. The revolution counter shows three revolutions of the big hand, or .300 inch, and the big hand has come to rest at 79 main dial divisions, or .079 inch. The sum of the two readings makes .379 inch.



Courtesy of Federal Products Corp

Fig. 29. Dial indicator shows the gage block to be 0 379 inch thick

Revolution counters are used on balance dial indicators, see Fig. 28, because, so many times when measurements are taken, the indicator hand revolves more rapidly than the eye can count its complete turns. A balanced dial, for instance, might seem to indicate +.012 inch when actually the hand has made a complete revolution and the actual measurement is .112 inch. In other words, the "tell-tale" informs the user which revolution of the large hand he is reading.

Other Factors Affecting Choice of Indicators

Commercial indicators provide a variety of lug arrangements for clamping or attaching them to test sets, gages and other apparatus and machines. Also a variety of shapes of contact points — spherical, flat, button, taper — are available. Like other measuring apparatus, various attachments such as lifting levers, right-angle or hole attachments, stem extensions, etc. are made available by manufacturers for use with indicators. The inspector might do well to study manufacturers' catalogs to become conversant with the various useful extra attachments that can be secured.

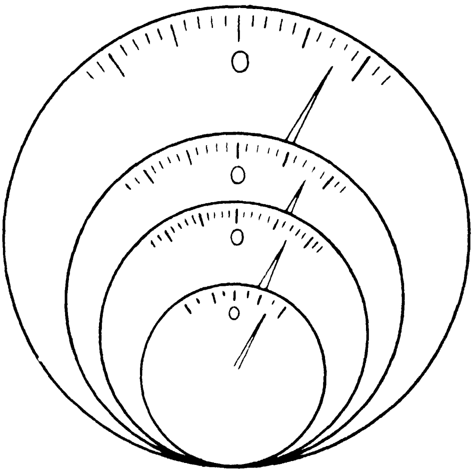


Fig. 30. Comparison of the relative sizes of the four standard AGD dials.

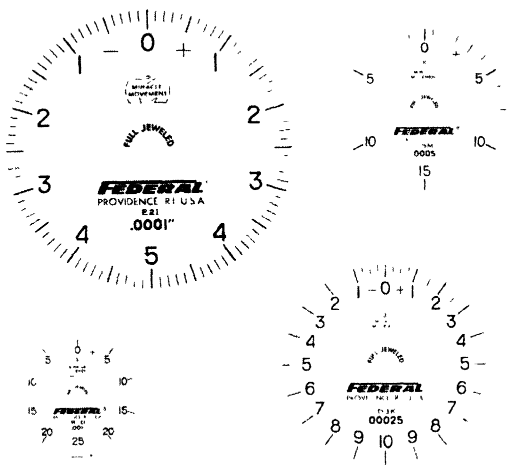
Assuming that the shop where the inspector works has available or will get a reasonable variety, in size, range and discrimination, of indicators, the inspector can use a little thought in regard to choosing the indicator best fitted to the job at hand. As for sheer size or diameter itself, AGD indicators vary from about $1\frac{3}{4}$ inches to $3\frac{3}{4}$ inches. Figure 30 shows the relative sizes of the four standard AGD dials available.

Selecting the Proper Size of Indicator

Several motives might influence an inspector in his selection of an indicator as to size, assuming that his shop's stock of indicators allows a reasonably free choice. Probably the natu-

ral tendency would be to use the larger diameter indicator, since its graduations are spaced farther apart — magnified — and it is "easier to read." If, because of physical limitations of the job, the indicator must be some distance from the eye, then this latter contention of easier reading is valid.

However, there are many setups where the largest size indicator is too big and bulky. It gets in the way. Hung on a test set its weight might cause deflection or tipping. Many times the use of a big indicator would compare to strapping the mantle clock on your wrist.



Courtesy of Federal Products Corp.

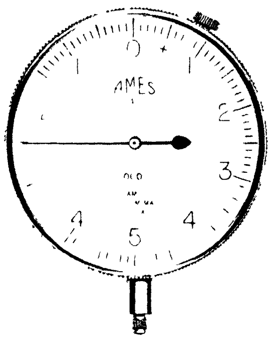
Fig. 31. Four of the several dozen available dial face graduations.

Even though the larger size indicators seem easier to read, it has been found that in many instances more accurate readings are secured and less mistakes are made when a smaller size indicator is deliberately chosen. The mere fact, probably, that you are forced to bring your eyes closer to the indicator, that you lean forward and perhaps squint a little, that basically you concentrate more on reading a small sized indicator tends to produce a more reliable result. The most common commercial indicator used is probably the 2 to 2¼-inch size.

The next choice, in connection with indicator selection, ties in with the graduations offered on the dial — the indicator's discrimination in other words. Ordinarily and commercially,

indicators come with dial divisions (and internal gear-train amplifications) so that readings can be taken in "tenths" (.0001 inch), "quarter-thousandths" (.00025 inch), "half-thousandths" (.0005 inch) and "thousandths" (.001 inch). Figure 31 shows four of the several dozen available standard dials.*

Coupled closely with the size of indicator to be used for a certain job, its discrimination and the sort of dial face best suited, is the question of the so-called range of the instrument. Commercially, dial indicators are more commonly supplied with one of the following total ranges or capacities: .010″, .020″, .025″, .050″, .075″, .100″, .125″, and .250″.



Courtesy of B. C. Ames

Fig. 32. Dial indicator having dial divisions of 0.0001 of an inch.

By indicator range is meant the nominal working travel of the contact point and spindle or gear rack. If an indicator with .010-inch range is selected, its use must be limited to ± .005 inch tolerances, for instance, while a .125-inch indicator can be used on size variations up to $1/8$ inch, etc. As a quick method for determining an indicator's standard working range (this figure is usually not stamped or printed on an indicator), multiply the number of dial divisions in thousandths by $2\frac{1}{2}$. As an example, the balanced indicator in Fig.

* Indicators are supplied in standard metric divisions — in millimeters from .001 mm to .010 mm. Also indicators can be obtained with .010″ dial discrimination or, for that matter, at special and higher prices, with almost any style or discrimination of dial division. Refer to manufacturers' catalogues.

32 is capable of measuring .010 inch in one revolution of the hand. The figures or digits on an indicator dial refer to thousandths of an inch (.001 inch) even though, as in the case of the indicator pictured in Fig. 32, the individual dial divisions register in "tenths" (.0001 inch). You can count on the indicator face in Fig. 32, 5 one-thousandth divisions down on one side of the dial and 5 more up the other side, or a total of .010 inch completely around the dial. Multiplying .010 inch by 2½ gives .025 inch as the working range of this indicator, or .0125 inch on either side of the zero position.

Reasons for Indicator Over-travel

Indicators have, of course, over-travel, i.e., the spindle will move several thousandths of an inch more than the standard range before coming to a full stop. At rest, the indicator hand is usually at the so-called nine o'clock position as in Fig. 32. When an indicator is moved into place for measuring, it is so located that the hand moves up to the 12 o'clock position or slightly beyond. (For a continuous dial indicator, this is done by rotating the indicator hand one-quarter turn clockwise; for a balanced dial indicator, one and one-quarter turns clockwise.) *This* position is the start of the working range, *not* the 9 o'clock station. After the 2½ revolutions of standard working range have been used up, with the indicator hand then at the 6 o'clock position, there is usually left at least another quarter-turn of extra travel (back to 9 o'clock again). Measurements are not supposed to be taken within the range of the preliminary quarter turn or in the final quarter turn of over-travel, but always inside the nominal 2½ turns of working range.

The reason for indicator over-travel is obvious since the combination of the setup and oversize in workpieces might well bring readings just a little beyond the end of the standard 2½ revolutions. The normally unused preliminary hand travel from 9 to 12 o'clock, however, is designed for another purpose. It is called starting tension. Look at the ghost view of an indicator in Fig. 25. The motion of the spindle and the internal workings are controlled primarily by a helical pull back spring which appears in Fig. 25 at the left of the spindle or rack gear. The compound gear train turning the hand can be traced out. But then there seems to be a gear left over — a larger gear to the right of the spindle which has a spiral hairspring attached to it. This gear, with its spring, acts as a balance

wheel. Gears will not mesh and operate freely without some clearance, however minute, between the tenth — without some backlash in other words. Any looseness, clearance or backlash could cause a displacement error between the actual travel of the spindle and the subsequent arc of the hand. The hairspring, however, imposes constant tension in the same direction against the gear train teeth and prevents error from backlash. It is to get the fullest advantage of the backlash correction of the hairspring plus putting some tension on the spindle pull back spring that a quarter turn is usually started on an indicator before actual measurement begins.

Factors Limiting Indicator Range

There are definite reasons why the indicator range is confined to 2½ turns except in special instruments that are particularly designed and specially fabricated and calibrated for longer ranges. It is practically impossible to manufacture a commercial instrument gear that will have perfect teeth around its entire periphery. It is equally difficult to mesh two gears so that no inaccuracy in ratio of rotation will appear throughout complete revolutions of the gears. But it is highly possible at assembly and calibration operations to select sectors of the larger gears to mate with the pinions with sufficient accuracy to assure the fidelity and reliability of the instrument, provided it is used within the range circumscribed by the mating gear sectors. (Something akin to this procedure appears during the manufacture of micrometers where the spindle screws are individually fitted, by lapping, to each nut.) Look again at the ghost view of a standard indicator mechanism in Fig. 25. It will also be seen that if the hairspring wheel is forced to turn too far, the hairspring itself will get wound up too tight and distort or buckle. Hence the usual limitation of indicator spindle travel to a range of less than ⅛ inch. In the so-called long range indicators — ¼-, ½- to 1-inch, some of which will be described in use farther on, most of the difficulties suggested above are overcome by special-size gears, pinions and with special compound arrangements. However, the longer the range demanded in an indicator, the greater the inaccuracies toward the end of that range. Manufacturers then do not necessarily guarantee ¼-dial-division repetition and plus-or-minus-one-dial-division calibration accuracy.

Effect of Gear-train Inertia and Friction

A gear train has inertia which must be overcome. The total inertia is increased by the length of the hand. Meshing gears set up friction; there is friction between the spindle and its bearings; the gear pivots turn in bearings (usually sapphire) and additional friction is present. The total effect sometimes makes an indicator appear slow or sluggish, a condition that seems to show up less as the indicator rack is moving in and more as the rack returns to the at-rest position after a reading is made. The general condition has been referred to (erroneously) as hysteresis.

Practically, the inertia lag is no hindrance, since the pointer usually comes to rest by the time the eye has adjusted itself to read the indicator. Practically, also, if an indicator lacked the natural inertia and friction of the gear train, if it lacked this damping effect; the pointer or hand might take so long fluttering to rest for a reading that some deliberate damping device probably would be provided in the instrument.

Mention is made of these indicator peculiarities — peculiarities inherent more or less in any mechanical amplifying system — because inertia, and especially friction, can finally so retard the complete motion of the gear train that the hand either will not quite come up to the final accurate reading or will swing beyond it and fail to return. If an indicator is dropped, if it has been mistreated, or if it becomes filled and clogged with dust, grit, oil or coolant, it will tire and should be turned in for overhauling and recalibration.

In use, the indicator dial's 0 is seldom or ever exactly at the twelve o'clock position. The dial is attached to the bezel and, when the bezel clamp is loosened, bezel and dial may be revolved either clockwise or counterclockwise to a desired zeroing position. However, zeroing is never done until there is pressure against the indicator point and until the indicator has registered about a quarter turn starting tension.

Use, Care and Calibration of Indicators

As has been said, an indicator is not, of itself, an independent measuring instrument. It is either clamped to a height gage or test set or it is an integral part of an indicating gage or comparator — see farther on. So used, it is to all intents and purposes a gage, because it does the actual measuring or comparing.

The matter of gaging pressure does not need to be considered, because the tension spring system in the indicator automatically exerts the pressure on the workpiece that is optimum for the accuracy of measurement required. The work is introduced or passed under the indicator point (or, as in the case of a moving height gage, the indicator point is moved over the work), a motion that can be made without regard to gaging pressure. Reasonable care should be used, however, not to thrust the workpiece and indicator point together. As in the use of gage blocks and other precision equipment, steady careful motions are the order of the day and the heavy hand is no more desirable here than in dentistry.

Most any dial indicator reading may show the sharp tip of the hand resting somewhere between two dial graduation lines. The regulation recited earlier for the steel rule applies here. Don't try to estimate the reading between dial divisions no matter how strong the tendency to do so. Decide on which dial division you will take as the reading. Or get an indicator with finer discrimination. If an indicator with .001-inch divisions is making you guess, try .0005-inch, .00025-inch or even .0001-inch graduations.

As with any other type of precision equipment, an indicator cannot be slammed around, dropped or tossed on a dirty bench and then be expected to register accurately. It should be kept reasonably clean from oil, chips, dirt or coolant. Ordinarily, an indicator does not have to be wiped thoroughly at each use for fear of subsequent rusting or corrosion. There are practically no ordinary shop conditions where temperature changes from handling, drafts, radiators or direct sunlight will affect its accuracy enough to be noticed.

If it is mistreated, if it gets dirt-clogged, bent or broken in some manner, it will tell you something is wrong. It is possible to damage a snap gage, vernier caliper, gage block or micrometer and fail to realize that it is not measuring correctly. But not so, ordinarily, with a dial indicator. Like a neglected watch, it just doesn't work.

Checking the Indicator for Accuracy

An indicator should be checked regularly for accuracy and repetition. Or, as with any other instrument you are stranger to, it may be best to check an indicator before putting it to use on measurements you wish to rely on.

Clamp it to a test set over a surface plate or machinist's flat. Wring a .100-inch gage block, say, on the surface under the indicator point, and then regulate the test set clamps and arm so that the indicator point touches the gage block — registers — and turns the hand the prescribed quarter revolution. Then, loosening the bezel clamp, turn the dial till the dial 0 graduation is directly under the tip of the hand. Slide the .100-inch gage block in and out under the indicator point a couple of times. The indicator should regain the 0 reading each time with a repetition error no greater than one-quarter of a dial division. (Be sure in such a test that any apparent error is not due to your manner of manipulating the test gage block. As it is moved in and out under the indicator contact point, it must be kept wrung to the surface under it.)

To calibrate or check the accuracy of the instrument, a .105-inch block, for instance, can be used next. The instrument should read + .005″ with an error no greater than plus or minus a dial division. The repetition test can be repeated with this block, if desired. The accuracy of the remaining range of the indicator can be tested in a similar manner, by using a succession of gage blocks increasing in size by steps several thousandths of an inch apart.

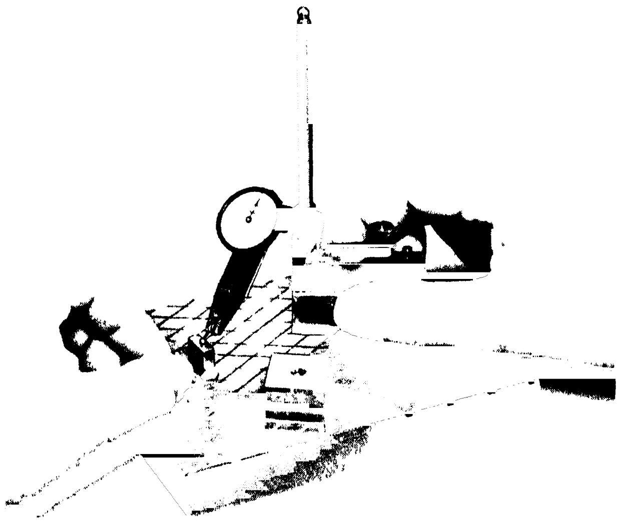
Where an indicator shows test errors exceeding a quarter of a dial division in repetition and plus or minus a full dial division in accuracy, it is best to return it to the manufacturer for repair. (Or a calibration chart can be made and future readings from the indicator in use can be corrected by the amount of actual error showing on the calibration chart.)

When an indicator becomes too sluggish, if it sticks, or is completely broken, it should be returned to the manufacturer. The amateur, though he feels capable of repairing the kitchen clock, should not try his skill on a precision instrument like an indicator. And don't take it to the local watch repair shop. Such artisans may well understand time and clock mechanisms but few of them have the necessary comprehension of precision measurement to properly know the end result of their repair effort even though an indicator does look like a watch. Send it back to the manufacturer.*

* Some gage repair departments in the larger shops do employ repair men who have been factory trained by instrument makers. They, in most instances, can supply expert repair service on indicators comparable to instrument factory skill.

Comparators and Dial Gages

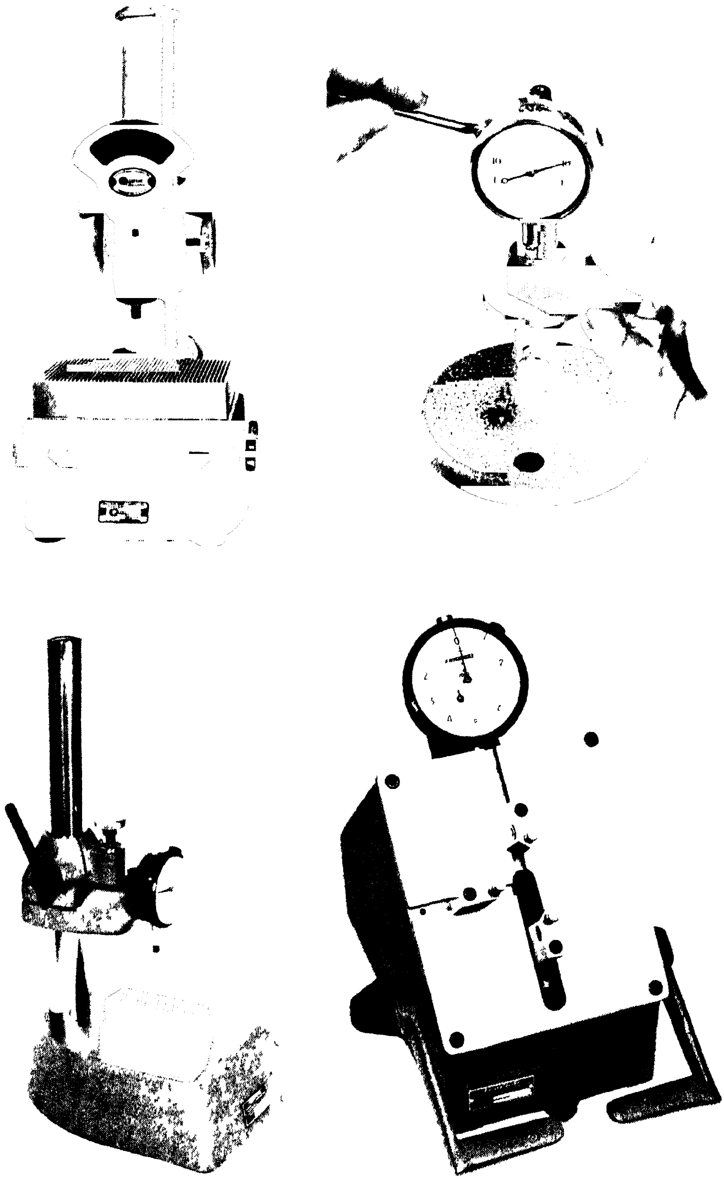
The test set, with its indicator, on a surface plate, forms a comparator. As its name implies, a comparator is an instrument that compares an unknown dimension with a known size. On a surface plate, of course, the usual procedure is to congregate a gage block stack equal to the blue print dimension being checked and zero the test indicator to it. Then, gage blocks are removed and the workpiece is tried under the test set indicator. Whatever the indicator reads, plus or minus, different from the original indicator 0, shows how much larger or smaller the workpiece is as compared to the master or gage block stack, in this instance. Figure 33 shows such an operation.



Courtesy of Federal Products Corp

Fig. 33. Dial indicator on a test set has been "zeroed" on a gage-block stack of height equal to the blueprint dimension being checked.

Cylindrical masters are also used with comparators. In fact, the general rule has been established that if the workpieces to be tested are round, the master should be round. Commercial master cylinders are made from hardened steel with even greater precision than standard plug gages. Errors in actual size, in ovality and taper, are usually confined within ten millionths of an inch of the specified size of the master.



Courtesy of Standard Gage Co
Courtesy of The L. S. Starrett Co
Courtesy of Federal Products Corp

Fig. 34. Various comparators which utilize dial indicators as a measuring element.

While perhaps the first thought in connection with dial indicators is their use in test sets, actually their most common use is on comparators and dial gages. In Fig. 34 are shown a variety of comparators and dial gages.

In studying comparators, and everlastingly while using them, the basic geometry of measurement and gaging should be kept in mind. More mistakes are made from ignoring or forgetting the correct geometry, from incorrect manipulation, than from any amount of intrinsic instrument inaccuracy. Usually, however, the instrument is blamed.

Any linear measuring instrument, any gage and any comparator must have first a reference point or reference anvil. Then it must have a measuring point, a movable or sensitive contact. The measurement must be secured over a true diameter, in the case of a cylindrical workpiece, and across the correct section, in the case of other shapes. In addition, a comparator must be correctly "mastered"; that is the indicator is first set by means of an accurate master to the dimension that is to be measured or, rather, compared.

Elements of the Bench Comparator

The ordinary bench comparator covers the geometrical requirements in the form of a reference anvil, *b* in Fig. 35, and the sensitive contact, *c*, which is really the indicator point. The reference anvil is many times referred to as simply the gage's anvil. Sometimes it is called a platen, or the table, and frequently it is dubbed simply the base of the gage.

Fig. 35 portrays the typical C-frame idea appearing in almost every type of outside diameter gage from the vernier caliper up. In the commercial comparator the C-frame connection is accomplished by an upright or post, *p*, in Fig. 35, fastened solidly to the base, *b*, and by an extending arm, *a*, which holds the indicator. Usually, on a commercial comparator the arm can be slid up or down the post and clamped by means of a screw handle, *h*, or some such device. Another glance at the outline in Fig. 35 brings to mind the familiar conception of the surface plate and height gage, of which the ordinary comparator is a practical adaptation.

The base, reference anvil, table or reference surface of the ordinary comparator is usually machined to the customary accuracy of the commercial surface plate in regard to flatness, warp and surface finish. On higher-priced and more precise

instruments, the comparator's base is more frequently referred to as the anvil or platen, and these surfaces are usually finished to accuracies in millionths of an inch, comparable to the machinist's flat.

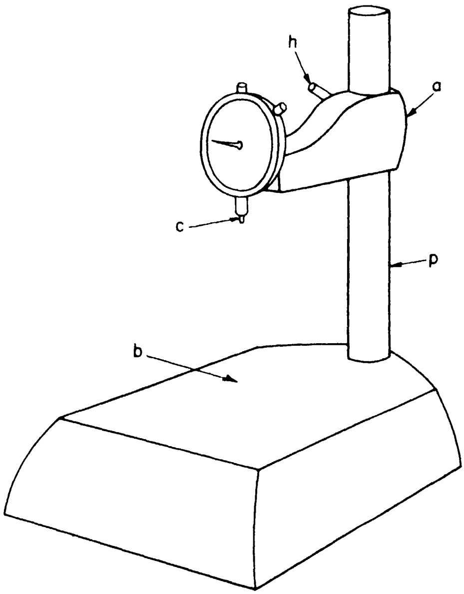


Fig. 35. Illustration of the C-frame construction of most outside diameter gages. Base *b*, column *p* and arm *a* comprise the C-frame.

Use of Interchangeable Indicators and Contact Points

On many commercial comparators of the general type illustrated in Fig. 35, the indicator is interchangeable. The selection of the proper discrimination of indicator — one with the correct dial graduations — can be based most usually on the rule that the indicator discrimination should be at least one-quarter the tolerance spread being checked, but need not be finer than one-tenth. If the blue print shows ± .005 inch, for example, an indicator with .001-inch graduations has sufficient discrimination in most cases. If, however, the tolerances are ± .001-inch then certainly the .0005-inch indicator should be chosen. (.0005 inch is one-quarter of a tolerance spread of .002 inch.) Where working tolerances in ten-thousandths must be checked, then the .0001-inch indicator or even the .00005-inch indicator is used. Fine discriminations in this neighbor-

hood represent the boundary between mechanical indicator ability and the finer discriminations and accuracies possible with air and electronic equipment — see farther on in this book.

Almost without exception, indicators are equipped with spherical hardened steel contact points. These may be of various shapes as *a*, *b*, and *c* in Fig. 36. So-called flat end contact points, as *d*, *e* and *f* in Fig. 36 can also be secured. For the

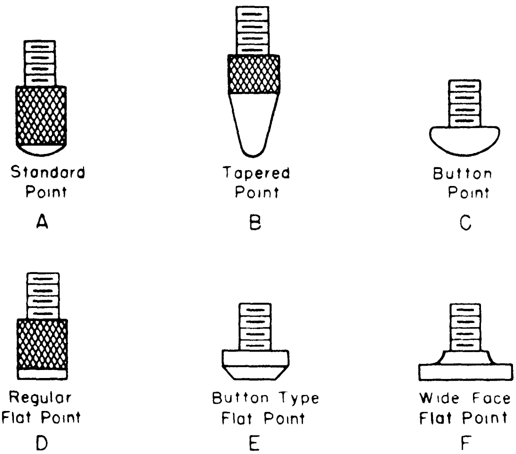


Fig. 36. Various shapes of contact points that are used with indicators.

sake of reducing wear, spherical contact points can also be secured with wear surfaces of chrome-plated steel, carbide, Norbide, sapphire or diamond; flat points (and anvils) come in hardened steel, chrome-plated steel, or in carbide, Norbide or sapphire. (It is said, as a common rule of thumb, that chrome plating increases the wear life of the contact point ten fold and that carbide, Norbide, sapphire and diamond will wear and last through 100 to 1000 times the gagings the hardened steel point can withstand.)

With the diagrams in Fig. 37 an attempt has been made to illustrate the attributes and shortcomings of flat-end and spherical indicator contact points and the comparison between them.

If a comparator's indicator is zeroed or mastered on a gage block stack as at A, Fig. 37, it is obvious that for ultimate accuracy the gage blocks must not only be wrung onto the

anvil but that the flat end contact point must also be wrung, in effect at least, onto the gage blocks. Otherwise, if the workpiece is cylindrical as at B, there can be a discrepancy between the diameter measurement read for the cylinder and the master reading over blocks which is not due to any actual difference in these two dimensions.

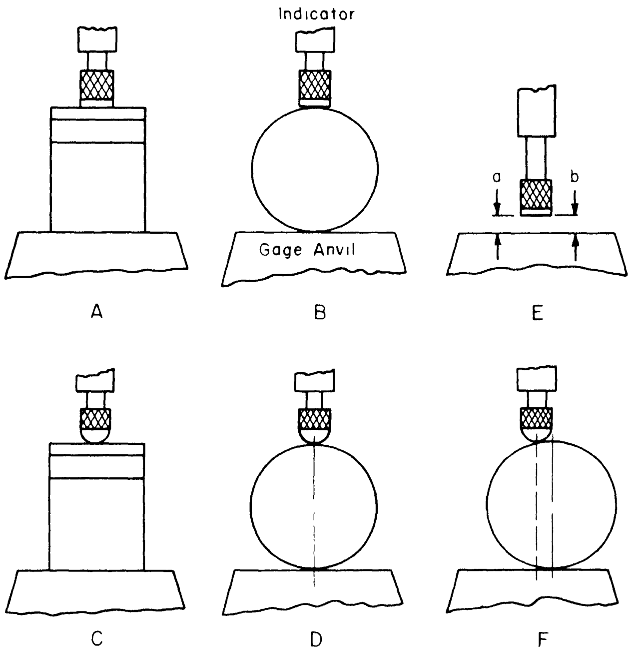


Fig. 37. Various applications for flat and round contact points. (A) Unsuitable application for a flat contact point. (B, C and D) Proper application of flat and round contact points. (E) Proper position of flat contact point. (F) Result of improper manipulation of round contact point.

Where the master is cylindrical, as in Fig. 37-B, and the workpiece is also a cylinder, the aforesaid discrepancy is overcome. Nevertheless the flat end contact point surface should be truly flat and parallel to the anvil as illustrated in diagram E of Fig. 37. In other words, a and b must be equal. Where the comparator has an adjustable arm, where the indicator and the contact point can be moved up and down above the anvil, it is obvious that the parallelism between a flat end contact point and the anvil will be maintained only as a matter of chance.

So, to get around this common difficulty, comparators are mostly usually supplied with spherical points as at C and D of Fig. 37. Since the contact of a sphere with either a plane or a cylinder is geometrically only a point, the difficulties of parallelism and wringing disappear.

The spherical point presents only one common error, which results from incorrect manipulation, as illustrated in Fig. 37-F; the inspector could happen to measure a chord of a cylinder as shown, rather than the true diameter. The proper technique with comparators, indicating gages and test sets is always to watch the motion of the indicator hand as the master or workpiece passes under the point, until it reaches the so-called high point — that indicator dial reading where the hand, after advancing in one direction, hesitates and then starts to recede or turn back.

Checking Ovality and Taper

In addition to strict outside diameter applications, the comparator very handily checks ovality and taper. For determining ovality, the workpiece is rotated until the indicator shows a maximum diameter. The workpiece is then rotated 90 degrees and another reading taken. If the piece is oval shaped, this second reading should be lower than the first, in fact it should be the lowest reading which can be obtained with the workpiece rotated through any angle. The difference between the first and second indicator readings represents the degree of ovality present. Taper, of course, is checked by indicating the workpiece at several points longitudinally along its axis.

On the whole, comparators will stand more abuse, careless handling and incorrect manipulation than any other type of linear measuring apparatus and still come up with accurate measurements. This is largely because a master is used and the workpieces are measured, or compared, under exactly the same conditions. A second reason for the comparator's nearly inevitable fidelity arises from the comparatively short range of indicator motion used. Even so, however, the comparator's base or anvil should be checked regularly for flatness and wear and it should be kept free from corrosion or dirt. Its adjustable indicator arm should always clamp up rigidly on the post or upright — the indicator should be tight to the arm. General looseness in any sort of adjustable measuring apparatus is not to be tolerated.

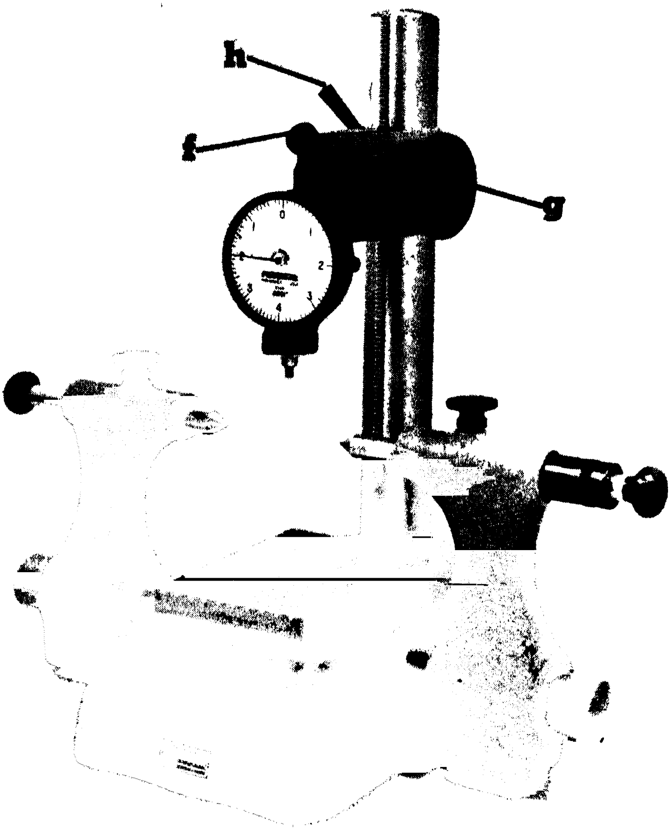


Fig 38 Commercial comparator gage equipped with accessories to simplify setting and operation.

Special Features of Comparator Gages

Figure 38 illustrates some of the accessories that can be obtained for commercial comparator gages which make their use, setting and operation easier or quicker. In addition to the clamping handle, *h*, many comparator posts are equipped with gear racks so that by turning a hand wheel like *g*, the indicating "head" can be more readily raised or lowered. Usually, too, this type of movable apparatus has a fine adjustment screw (*f* in Fig. 38) for the easy final zeroing of the indicator. The comparator in Fig. 38 also displays a set of attachable centers for the ready testing of ovality, curvature and warp in cylindrical workpieces. So-called "serrated" platens or anvils,

as in Fig. 38, can be secured with diagonal grooves that are purposely milled into an otherwise perfectly flat smooth surface so that dirt, dust or chips will be readily scraped into them, thus keeping the actual anvil measuring surface more or less automatically free from that type of possible measuring error. V-blocks are, of course, used on the platens of comparators, just as they are on surface plates.

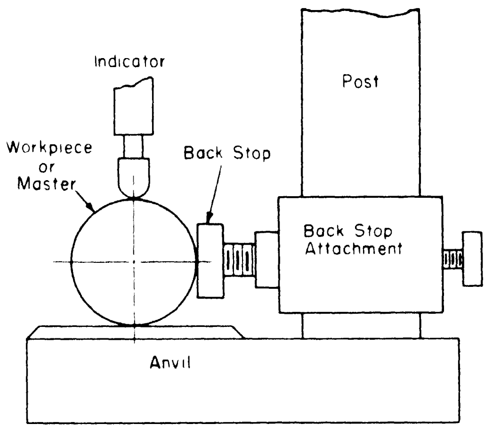


Fig. 39. A comparator may be equipped with a back stop against which the work-piece butts in the correct position under the indicating point, thereby eliminating the error shown in Fig. 37 (F).

The sketch in Fig. 39 brings up the principle of the so-called "back stop." A back stop, as its name implies, is a fixture attached to a comparator (usually to the post) against which the workpiece butts or stops in the correct position under the indicator point. Its use eliminates the sort of off-center error illustrated in Fig. 37-F. When a back stop is properly adjusted, a cylindrical workpiece will come automatically to the correct measuring position with the indicator point properly over the diameter. The workpiece will occupy the same position as a cylindrical master.

The right way to set a back stop is to loosen its clamping screw or device, move the master or a workpiece under the indicator point until the "high" indicator reading is obtained and, bringing the back stop against the master or sample workpiece, tighten it in that position. From then on, all similar pieces are in position for gaging if they rest against the back stop.

Portable Dial Indicator Gages

Up to this point on the subject of comparators, the idea of bench gages has been described — the situation where the workpiece is brought *to* the gage. The comparator principle is applied however to portable gages — to the situation where the *gage* is brought to the work. Two types of portable comparators are shown in Fig. 40.

Courtesy of Federal Products Corp

Fig. 40 Two types of portable comparators

The comparator principle still applies, however, in that the portable indicating gage possesses an indicator, a sensitive or measuring point, and a reference surface or anvil, that are held in proper position by a C-frame. Portable comparators are almost inevitably equipped with back stops. Portable indicating gages of the comparator type are mastered, in the same manner as their bench prototypes, their indicators zeroed, and the measurements taken are comparisons with those of the master used.

The Indicating Snap Gage

The sketch of an indicating snap gage in Fig. 41 will serve to bring out the usual geometry and mechanics of this type of instrument. Contrary to the bench-type comparator, the reference or fixed anvil on a portable gage (*f* in Fig. 41), is usually above the sensitive contact. It rests on the workpiece. By designing in this manner, the solid anvil supports the weight of the gage. If it were the other way round, the sensitive contact and the indicator would register some of the weight

of the gage and the reading would be a mixture of the comparative diameter of the workpiece and the added contact and indicator deflection caused by the gage weight and the pressure of the hand applying the gage. The fixed contact too, in commercial gages, is equipped with a screw, tongue or clamping mechanism whereby the reference anvil can be raised or lowered, thereby increasing or decreasing the overall capacity of the instrument by widening or narrowing the span of the jaws.

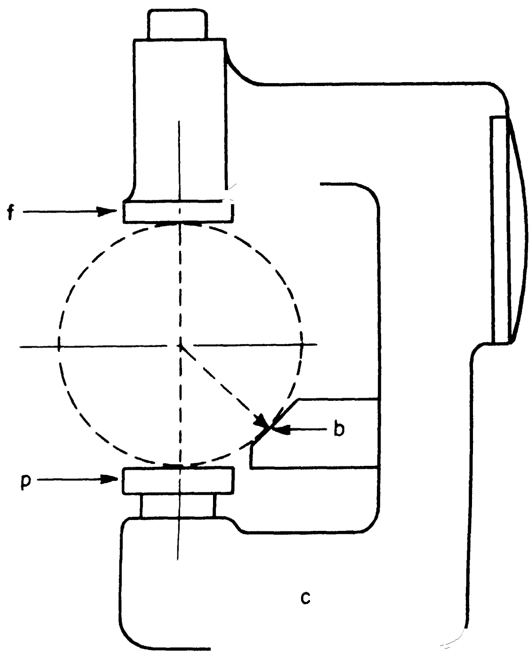


Fig. 41. Schematic diagram of an indicating type snap gage.

Usually, in portable gages, the back-stop face (*b* in Fig. 41) is cut at a 45-degree angle, thus, geometrically, simulating the V-block. The 45-degree back stop assists the inspector in holding the workpiece in the proper position for correct gaging.

The motion of the sensitive contact (many times referred to as the "lower anvil"), shown as *p* in Fig. 41, is transmitted to the indicator, by various designs of plunger movement, pivot or spring mechanisms, depending on the make of instrument, all of which are contained inside the frame *c*.

Using the Right Gaging Methods

The professional touch to be learned in the use of indicating snap gages is to let the gage do its own work. The matter of suitable gaging pressure is self regulated in the spring loaded mechanism of the sensitive contact *p*. No more finger pressure is needed to gage a workpiece than that which will slide the contacts over the workpiece. As soon as the gage has suitably "homed" on the workpiece, release the hand pressure and simply support the gage sufficiently with the finger tips to prevent its slipping away from the workpiece. Examination of Fig. 42 will make this instruction clearer.

Courtesy of Federal Products Corp

Fig. 42. (Left) Method to be used in applying an indicating snap gage to a work-piece. (Right) Checking the measuring surfaces of an indicating snap gage for parallelism and flatness

The proper manipulation of a portable comparator, then, consists in starting the fixed or reference anvil on to the work-piece, using the fixed anvil as a pivot, and swinging the lower or sensitive contact, *p*, into position, continuing the swinging and pushing motion until the contact of the back stop *b* completes putting the gage in position. Then relax the finger hold on the gage.

Like its larger relative, the bench comparator, the portable indicating gage is rugged — at the same time sensitive and accurate — and will withstand a great deal of abuse. It should be kept clean, and, as much as possible, away from oil, coolant, dirt and chips. The effect of hand temperature must be watched. Steadily gripping a portable indicating gage can affect its accuracy, sometimes as much as .0005 inch, because of the heat absorbed by the gage's C-frame and the subsequent

expansion of the frame. Take a measurement and set the gage down; don't handle it like a coal shovel or a garden fork.

Checking for Proper Calibration

Since the ordinary portable comparator or indicating snap gage is used with a master it does not ordinarily need to be calibrated or checked. However, it is a good thing every so often to test the calibration of its indicator and the parallelism of its jaws, if the latter are flat. This is done, usually, by selecting a gage-block stack representing the nominal capacity of the gage. The reference anvil is adjusted to the gage blocks until the indicator registers the customary quarter turn. The gage block stack is then slightly wrung into final position between the gage contacts and the indicator is zeroed. The operation is repeated with gage block stacks .001 inch, .002 inch or .005 inch longer or shorter, but *without* changing the setting of the indicator. The indicator should faithfully reproduce the increase or decrease of gage-block stack length with suitable plus or minus readings.

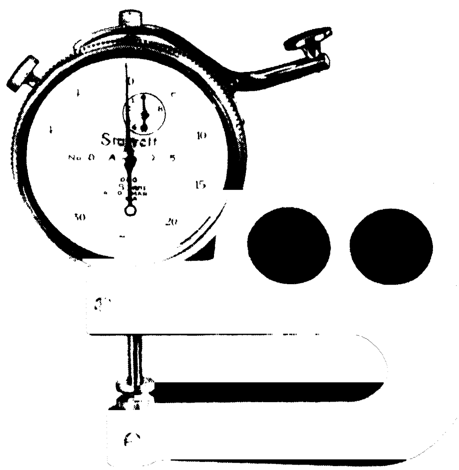
It is wise also, of course, to give a portable snap gage a repetition test on a cylindrical master every so often. The repetition error should not exceed one-quarter of a dial division on the gage's indicator; calibration, flatness, and parallelism errors should not be greater than a dial division.

With the gage-block stack available, it is easy to check the parallelism between the reference surface and the sensitive anvil. Add to the equipment a standard instrument measuring roll or wire plug gage 1/16 inch to 1/8 inch in diameter. The reference contact is adjusted down onto the measuring roll riding on the gage blocks until the indicator registers. Move the measuring roll back and forth and from side to side and watch the indicator hand; any variation in parallelism will show up as a variation in indicator readings. Where the sensitive contact is spherical or cylindrical in shape, the parallelism check is, of course, unnecessary.

The flat anvils of a portable indicator gage should be checked occasionally for flatness. If considerable care is used, the test can be made by sliding a steel ball, Fig. 42, between the anvils registering on it and watching the gage's own indicator. Humps and hollows in the anvils will be transmitted through the ball and the gage mechanism to the indicator. The optical flat test, to be described farther on, is more accurate.

Wear on the gaging contacts of portable gages is reduced, commercially, by the use of chrome-plated steel, carbide, Norbide or sapphire for contact surfacing in place of hardened steel. However, because the portable comparator-type indicating gage is used always with a master, the effects of wear, uneven anvils and lack of parallelism are not usually noticed until such errors have reached a comparatively extreme stage.

One more recommendation for this general type of gage should be mentioned. Because a dial indicator and a sensitive contact form its basic measuring principle, workpiece conditions like taper, ovality, crookedness and lack of parallelism can be readily seen or explored for, conditions which are much more difficult to detect with conventional micrometers and virtually impossible to find with fixed snap gages.



Courtesy of The L. S. Starrett Co.

Fig. 43. One type of direct reading dial indicator gage.

Dial Indicator Gages are Direct Reading

Dial indicator gages embrace a line or selection of direct reading instruments, in contrast to comparators. For this type of gage, the indicator is equipped with a continuous dial, instead of the balanced dial which is universal on comparators, and a revolution counter or tell-tale hand. The indicators are

of special design and are constructed to accommodate ranges and gage capacities of $\frac{1}{4}$ inch, $\frac{1}{2}$ inch or 1 inch. Such gages are invariably equipped with lifting levers, so-called, or some mechanism by which the indicator contact point can be readily raised and lowered. One such type of instrument is illustrated in Fig. 43. The familiar C-frame caliper principle is apparent, to which the solid, lower or reference anvil is attached. In contrast to the portable snap gage comparator (see Fig. 41) the corresponding type of direct-reading gage comes with the anvil arrangement reversed because of mechanical difficulties. In using the direct reading gage, care must be used to hold the lower or solid reference anvil against the work and not allow an erroneous indicator reading because of unsuspected pressure on the upper or sensitive contact.

Using the Dial Indicator Gage Properly

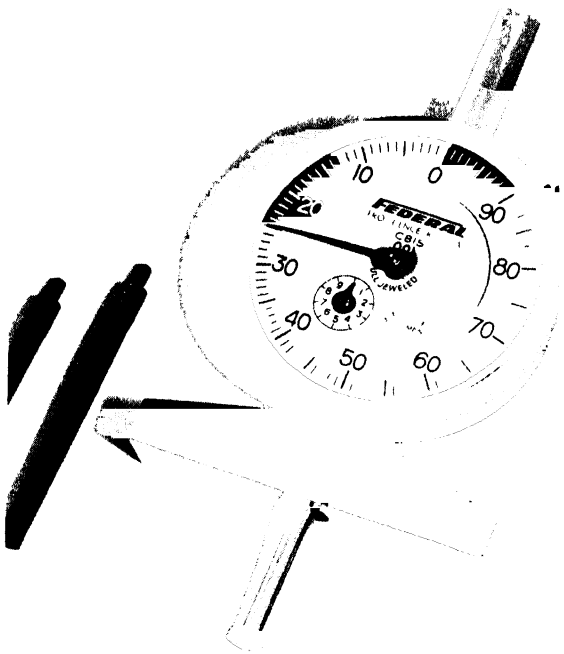
Harking back again to the idea of the professional touch in gaging and inspection, there are one or two techniques in connection with using the sort of direct-reading, dial-indicator gage illustrated in Fig. 43 that the new inspector would do well to remember. If the gage is equipped with flat-surfaced anvils, they should be checked now and then for parallelism both at the at rest position shown in Fig. 43 and near the other end of the gage's range where the sensitive contact is raised farthest above the reference anvil. The latter test can be made with a combination of gage block and a small diameter precision measuring roll.

It is also good practice to check the gage's accuracy near the range where it will be ordinarily used. Suppose, for example, the indicating gage has a total range of $\frac{1}{2}$ inch but it is to be used mostly on workpieces whose diameters will vary between about $\frac{1}{8}$ inch and $\frac{3}{8}$ inch. Test the gage's accuracy with a $\frac{1}{4}$-inch gage block or master cylinder. If it is accurate, within plus or minus a dial division, at the $\frac{1}{4}$-inch station, it is fairly safe to presume its accuracy at $\frac{1}{8}$-inch or $\frac{3}{8}$-inch readings. Another similar procedure is to check or master the gage on a gage-block stack or master cylinder that equals the nominal blue print specification of the workpieces to be inspected and then, in effect, use the gage as a comparator.

Generally, the discrimination of an indicator used on a direct-reading gage is tied in with the gage capacity. If .0001-inch discrimination is required for dial graduations on

the indicator, the range of the gage cannot exceed .250 inch. The 1-inch range instrument is equipped with a .001-inch division dial and the ½-inch gage with a .0005-inch division dial.

Long-range indicators are used on bench gages of the general type illustrated in Fig. 35. Such equipment is especially useful for checking thickness, shoulder heights and depths and other miscellaneous dimensions as well as outside diameters.



Courtesy of Federal Products Corp.

Fig. 44. Dial indicator designed for use as a depth gage.

A special adaptation of dial-gage design, a depth gage, appears in Fig. 44. The inspector is again urged to study gage makers' catalogues, bulletins and advertisements to become up-to-date on the various types of modern indicating gages and equipment available.

Indicating Micrometers

The subject of longer-range, continuous-measuring, dial-indicator gages cannot be concluded without mention of indi-

Courtesy of Federal Products Corp.

Fig. 45. Indicating type micrometer.

cating micrometers. While an indicating micrometer, Fig. 45, seems to be essentially the same as the conventional micrometer described in Chapter 5, it has, other than its indicator and indicator mechanism, several different and valuable characteristics.

In the first place, the reference anvil is spring loaded to impose a constant pressure of two pounds on the workpiece, as shown in Fig. 46. As the micrometer spindle is turned down

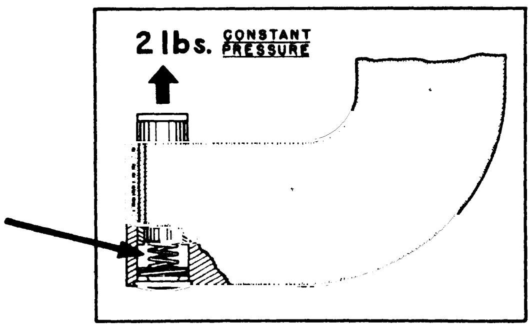


Fig. 46. Cutaway view showing the spring-loaded reference anvil of the micrometer in Fig. 45.

on the workpiece in the customary fashion, the spring-loaded reference anvil yields as two pound micrometer screw pressure is reached and the movement of the anvil is transmitted through an indicator gear train, enclosed in the frame of the

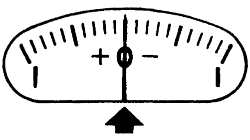
micrometer, to the indicator dial. When the dial reads 0, the mechanism is balanced and the micrometer can then be read in the customary manner.

How Accurate Readings are Obtained

The practical advantage offered by the spring-loaded reference anvil is that correct, consistent gaging pressure is always applied to the workpiece. It is easily possible to obtain an erroneous reading with the conventional micrometer — erroneous from several tenths to several thousandths — by varying the amount of thumb-and-finger pressure on the micrometer thimble, spindle and screw thread. Let two people try to measure the same diameter and usually different micrometer readings will be reported, because no two workers ordinarily exert the same amount of force on a micrometer thimble. The indicating, spring-loaded micrometer eliminates this universal, potential error. Two or twelve people using it will get the same reading.

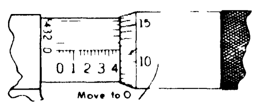
Although the indicating micrometer is vernier equipped, it is handier to use the indicator for reading fractions of a thousandth of an inch. Following the directions in Fig. 47:

1. Set the Indicating Micrometer anvils on the piece being measured and turn the spindle until the Mikemaster indicator hand swings up to **dial zero.** You now have stable pressure (2 lbs.) on the work.

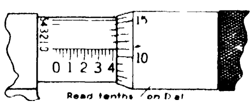


2. Read barrel and thimble. Thimble graduations may not match barrel 0 reference line.

   (Reading: .436″ plus some tenths)



3. Turn thimble up, in same direction until its next graduation matches barrel 0 reference line.



4. Then read tenths (.0007″) directly on the Indicator.

   The correct reading is .4367″

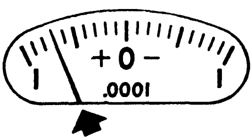
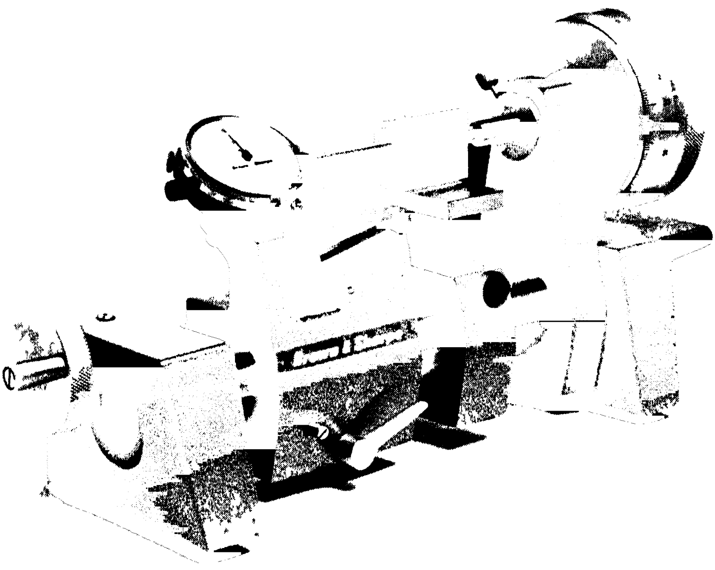


Fig. 47. Operating instructions for the indicating micrometer of Fig. 45.

The Direct-reading Bench Micrometer

The big brother of the portable indicating micrometer is illustrated in Fig. 48, a direct-reading bench instrument known as the Ultra-Mike. This instrument has the spring-loaded, constant, correct pressure reference anvil. Its indicator comes to the zero position to signal that the correct pressure has been applied to the workpiece by turning the spindle — in other words, when the Ultra-Mike indicator registers 0 it is the signal for reading the micrometer spindle and thimble. The thimble

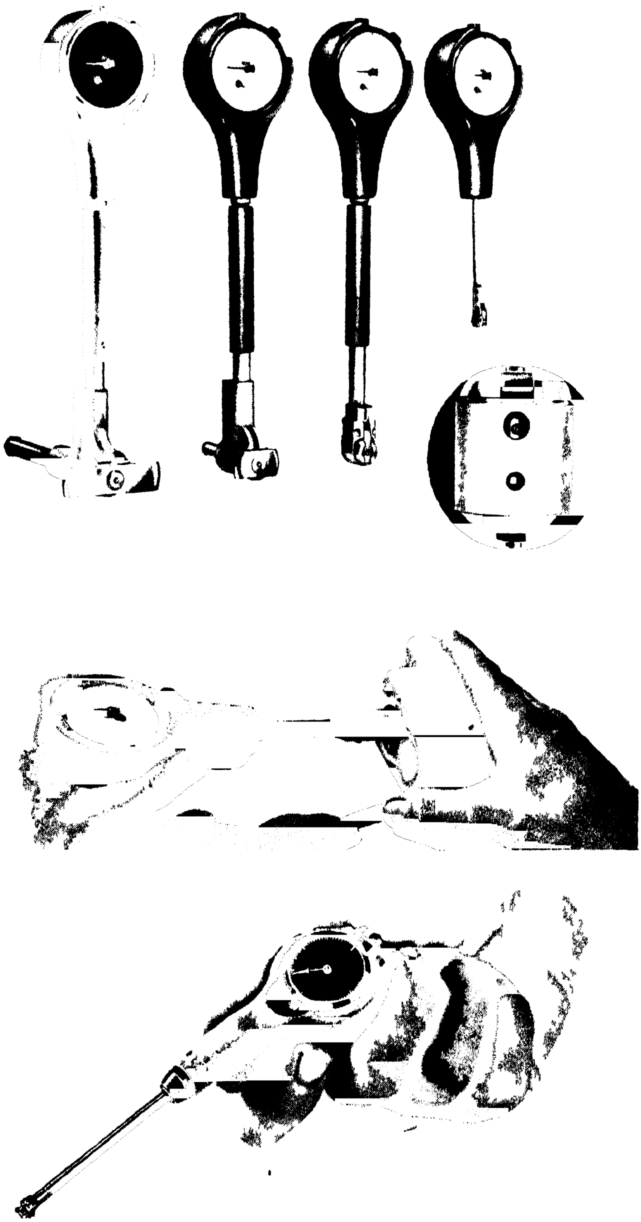


Courtesy of Brown & Sharpe Mfg Co

Fig 48 Direct-reading bench micrometer

is enlarged so that it can be read directly to .0001 inch. The capacity of the Ultra-Mike can be increased over the 1-inch range of its spindle because the reference anvil is contained in a tail stock which can be moved back and forth. Initial settings of the tail stock in even inch increments away from the spindle are obtained with the use of 2-inch, 3-inch and so on, gage blocks. An elevating table makes the introduction of workpieces between the Ultra-Mike anvils easier.

* Trademarked name. Brown & Sharpe Mfg. Co., North Kingstown, R. I.



Courtesy of Federal Products Corp

Fig 49 Commercial types of indicating bore gages

Comparators for Internal Diameters and Indicating Bore Gages

Thus far, the discussion of dial indicator gages and comparators has been based almost entirely on the measurement of outside diameters, thicknesses or depths. Gaging equipment of similar principle has been devised for measuring inside diameters — holes or bores. Some idea of the commercial types of this apparatus available can be gained from an examination of Fig. 49.

Indicating bore gages also can be used to check the width of slots, to measure between two planes or parallel surfaces, performing a function similar to the square plug gage. It goes without saying that extra care in manipulation is to be used in order not to measure unconsciously on some diagonal rather than on the true perpendicular axis between the two planes.

One type of indicating bore gage, A in Fig. 49, is provided with a *pair* of reference contacts or solid anvils and a single sensitive or movable contact all arranged 120 degrees apart. Another variety, B, is furnished with only the single solid contact or reference anvil directly opposite the sensitive contact, which might be compared to the familiar machinist's spring caliper. Still another variety has this same arrangement of opposed single contacts but they are equipped with special centralizing devices, as in C and D.

At this point it would be well to review the discussions starting on Page 76 concerning the reference point, measured point, repetition and especially the description on Page 84 of the correct use of ordinary inside calipers because the same geometry and principles apply to the proper use of indicating hole gages and comparators. Indicating bore gages must be carefully centralized ("rocked" is the shop term) and manipulated to be sure the true diameter is being measured. While gage makers provide so-called centralizers, they are not necessarily fully automatic and the inspector is not absolved of the blame for getting an incorrect measurement where he trusted a centralizing device too far. An attempt has been made in a series of "right and wrong" diagrams in Fig. 50 to point out possible errors in the manipulation of hole gages.

This type of gage is limited, in any individual use, to the range of the indicator. Depending on the discrimination and precision desired, indicating bore gages have capacities vary-

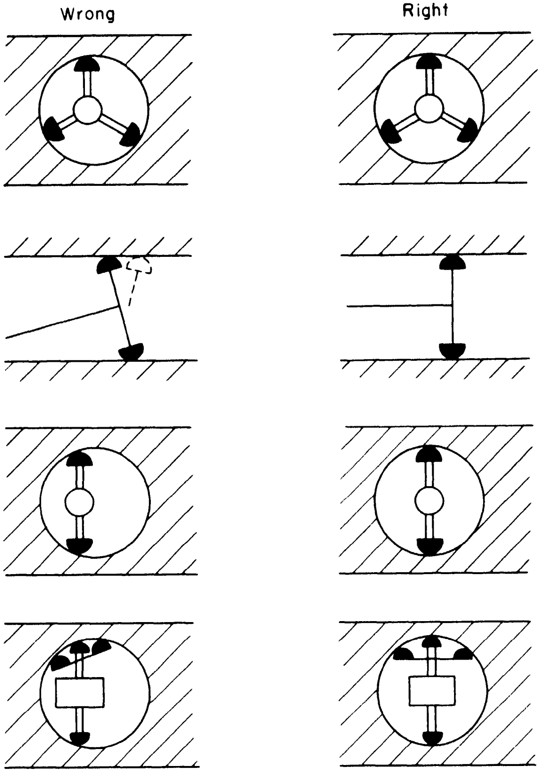
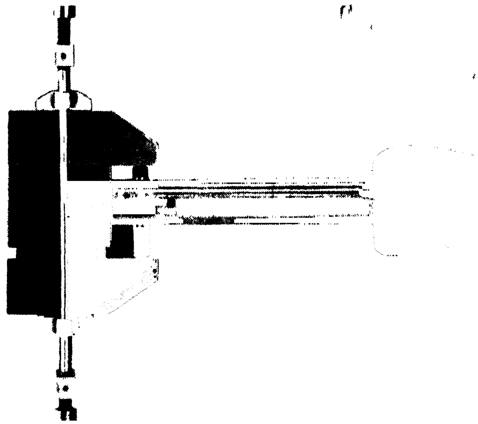


Fig. 50. Diagram showing the results of correct and incorrect manipulation of hole gages.

ing between .010 inch and .250 inch. However, the total capacity of the average commercial hole gage may be extended over about an inch range because the reference anvil can be unscrewed from the gage and a longer or shorter solid contact substituted.

Mastering Indicating Bore Gages

Indicating bore gages are, almost without exception, comparators and must be "mastered." And following the rules of the game which say that if a comparator is to be used to measure cylindrical work it should be mastered on a cylinder, or on a rectangle if it is to be used on rectangular work, the bore gage is best mastered in a master ring of suitable internal diameter. In other words, the average commercial bore gage is not a complete gage unless it is accompanied by its master ring; the two go together like bread and butter. To all intents



Courtesy of Dearborn Gage Co.

Fig. 51. Mastering an inside comparator in a gage block caliper.

and purposes, master rings are standard American Gage Design (A.G.D.) ring gages and the gage is "set" to the ring. The dial of the gage's indicator is "zeroed" at that location of the indicator hand where, as a result of rocking and centralizing, it reaches its maximum swing and starts to turn back. (Review the identical principle and geometry on Page 243, preceding, describing the correct way to "master" a comparator's indicator on a cylindrical master.)

Theoretically, at least, an inside comparator can be mastered in a gage-block caliper as illustrated in Fig. 51. But to manipulate or hold the gage and read the high point of the indicator hand's swing takes the touch of an expert; it is so easy to "master" it incorrectly, on a diagonal, as indicated by the dotted lines in Fig. 52 at A.

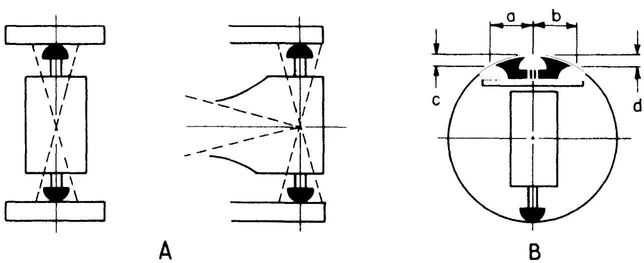


Fig. 52. Dotted lines in (A) indicate incorrect mastering positions for operation shown in Fig. 51. (B) Comparator gage equipped with centralizers to reduce the possibility of incorrectly mastering and using the gage.

Effect of Error in Bore Gage Centralizer

If the gage has a centralizer, that centralizer must have been manufactured, assembled and set absolutely accurately. The geometry of the situation is outlined in sketch B of Fig. 52. Dimensions a and b — the center-line relationship between the centralizer tips and the axis of the sensitive gage contact — must be equal. Similarly, the centralizer cannot be tipped, twisted or offset; dimensions c and d must be alike. If dimen-

Courtesy of Federal Products Corp

Fig. 53. Indicating equipment which utilizes spreading contacts similar to those used in a micrometer gage. A trigger-type lever mechanism retracts the contacts.

sions a and b or c and d are unlike to the extent of .001 inch, an error in measuring the I.D. of a hole up to .0002 inch is easily likely where the gage is "mastered" in the rectangle of a gage-block caliper and then used in the cylindrical section of a bore.

On the other hand, even though a centralizer is not absolutely true geometrically, it will have little effect on the accuracy of the bore measurement if the gage is "mastered" in a ring and its indicator "zeroed," because the gage is working

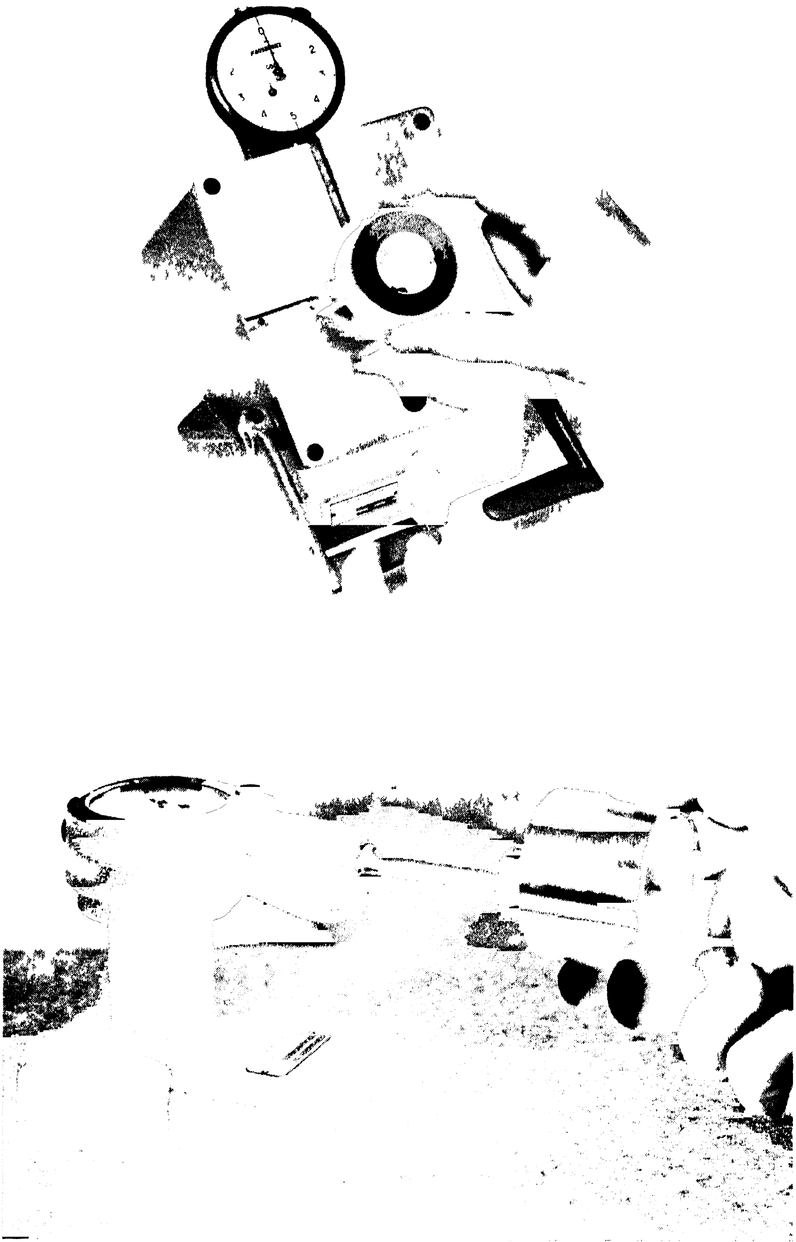
under the same conditions. This statement holds true with mechanical errors or wear in a centralizer up to about .010 inch. A bore gage's centralizer when twisted, warped, worn or offset more than .010 inch can produce an instrument error even though the gage is mastered in a ring.

Proper Manipulation of the Indicating Bore Gage

Indicating equipment of a design similar to that of a micrometer plug gage is shown in Fig. 53. In this case, the spreading contacts are moved outward by a spring inside the plug and the indicator registers the amount of that movement in tenths, half-thousandths or thousandths of an inch. The contacts are retracted by a trigger-type lever.

Centralizing with this sort of gage is accomplished by having the "plug," which is really a metal skirt, made to within ± .001 inch of the minimum inside diameter that is expected to be measured. In other words, if the nose of the plug itself will not enter the hole, the hole has been bored at least .002 inch undersize. Gages of this character usually have a total operating range of .010 inch. They are, to all intents and purposes, single-purpose gages, like equivalent, fixed, conventional plug gages, and almost always a particular plug with its expanding contacts must be inserted in the gage head for each hole size. Since these gages are comparators, they must be mastered, and each plug is usually accompanied by its equivalent master ring gage.

In mastering and using this type of gage, as with its prototype the micrometer plug gage, it must also be rocked a trifle to assure suitable centralization. If the contacts are retracted by the trigger, if the plug is inserted in a hole, and if the spring loaded contacts are released to press against the sides of the hole — all this without rocking or "homing" the plug a little — the indicator hand will be seen to move, creep a little, before settling into a final reading. What the indicator is trying to tell you is that the gage is not yet set on the true diameter. When, after a trifle of rocking and "snugging" the gage plug in the hole, the indicator settles down — if you get repetition in other words — then the gage is properly centralized. One of the things to be learned from use and experience with all types of indicating gages and comparators is that the motion of the indicator hand will tell you of errors in the gage or its manipulation.



Courtesy of Federal Products Corp

Fig. 54. Bench types of indicating hole gages. With these types of gages, the work-piece is brought to the gage rather than the gage to the work

Up to this point, the discussion has been confined to portable indicating bore gages — to the situation where the gage is brought to the work. Bench type indicating hole gages, as shown in Fig. 54, are also available for the situation where the workpiece is brought to the gage. And here, one more bit of geometry and professional manipulation should be described.

When the bore gage is brought to the work, the solid reference contact or anvil touches the workpiece first, as shown at *a* in Fig. 55-A. It bears the weight of the gage and the operator's hand and acts as the pivot point about which the gage is rocked, until the sensitive contact at *b* is truly opposite. But

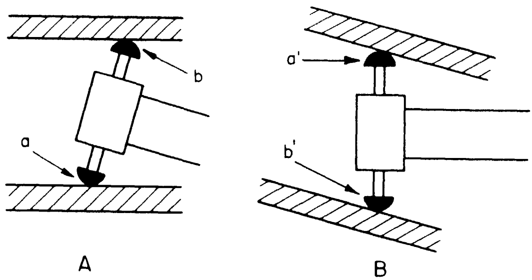


Fig. 55. Methods of manipulating bore gages: (A) For portable bore gages the solid reference contact, *a*, touches the work-piece first. (B) For bench-type gages, the reference contact, *a'*, is on top and the work-piece is rocked or pivoted until the sensitive contact *b'* is diametrically opposite.

when the work comes to the gage, the situation is reversed. As shown in Fig. 55-B, the reference anvil, *a'*, points up, the workpiece rests on the solid contact and is rocked or pivoted about it until the sensitive contact *b'* is diametrically opposite. Thus, our fundamental rules for reference and measuring points are lived up to.

Hole Conditions Which Must be Anticipated

It probably seems rather obvious, now, that with internal indicating gages and comparators, hole conditions such as ovality, taper, hour-glass and barrel shape, and bell-mouth, can be explored for and readily detected. In fact, the great advantage of indicating equipment over the standard plug gage is this ability. Always, when measuring an I.D. with an indicating bore gage, stop long enough (a) to explore for extraneous conditions and (b), if they are discovered, find the *minimum* diameter, for after all, it is the minimum diameter

of a hole which is effective when a shaft or cylinder is assembled in a hole.

Cement in your mind, by studying the diagrams in Fig. 56, the presence of ovality, barrel shape, hour-glass shape or bell-mouth, and taper, some of which or all of which will undoubtedly appear to some degree in practically every bored hole checked by an inspector. These sketches show in dotted lines how the conventional plug gage may check the minimum diameter, but little else, and, with arrows, how explorations with the contacts of indicating gages disclose actual conditions.

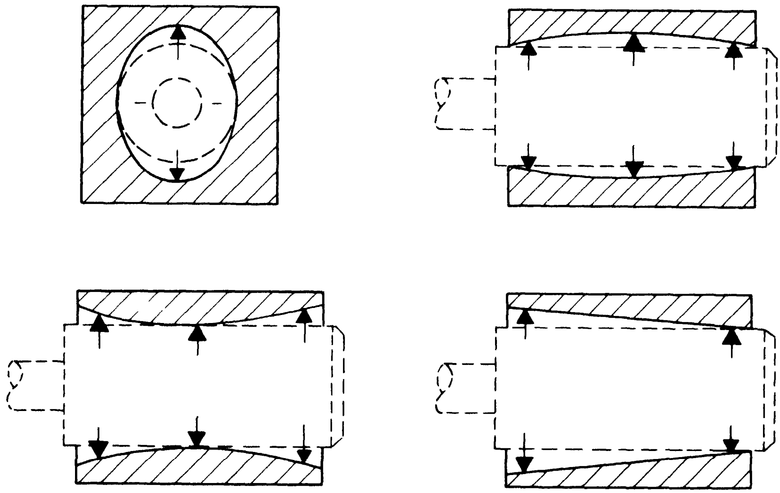


Fig. 56. Various hole conditions which a conventional plug gage will not indicate but which may be explored with indicating-type gages.

Anyone who knows about machine design realizes that a bearing, for instance, must have so-called bearing area — enough *area* of metal in contact between shaft and bearing to withstand the pressure imposed on it. Pressure is usually thought of in terms of pounds per square inch. The sketches in Fig. 56 point out that the shaft and bearing, under the conditions illustrated, would have practically point or line contact resulting in an uneven distribution of bearing pressures which may result in vibration, accelerated wear and premature breakdown. Thus, extraneous conditions such as ovality may be more serious than actual digressions from the specifications in diameter tolerances, clearances and allowances.

Care and Checking of Indicating Gage Equipment

The greatest danger in the use of indicating gages may be expressed by saying that familiarity leads to overconfidence. We pick up a portable indicating gage or go over to a bench comparator and use it without the necessary preliminary precautions to assure ourselves we are going to read the accurate results we require. Where such an instrument has not been used lately, the following routine is worth following:

1. Assuming the indicator has been checked for repetition, calibration and free running, look over the way it is clamped to the test set, comparator frame or gage. Any detectable shake or looseness is not to be tolerated.
2. Checks for looseness or play should be applied to comparator posts, bases, clamping handles, fine adjustment mechanisms and anvils. It is easy, for instance, to rely on the accuracy of a comparator and find afterward that the reference anvil was not securely clamped down.
3. In the case of portable gages, especially those with adjustable reference anvils (which are supposed to be solid), and also in the case of bore gages with adjustable or changeable extension anvils, test the anvils and extensions to be sure they are secure and can't wiggle loose.
4. If gage back stops are to be used and relied on, make sure they are also clamped tight in the proper location.
5. The sensitive contact points on many portable gages and bench comparators are tipped with wear resisting carboloy, Norbide, sapphire or diamond inserts. It is well to try such tips to see that they haven't loosened in previous use. Also examine them under a glass. If they are cracked, chipped or badly scored, their surface conditions may prevent accurate readings or repetition or they may scratch and scar the work.
6. If opposing anvils are supposed to be flat and parallel, give them the wire or ball test (see page 102).
7. Usually portable indicating gages and bench comparators are as neglected as the back of a small boy's neck. If dirt, dust, grit, chips, grease, scum and coolant will interfere with the accuracy of gage blocks, they will also offset the precision of comparators. Clean an instrument thoroughly at each use, and, after you are through with it, rust proof exposed iron or steel surfaces.

8. Make as sure of the reliability of master discs and master rings as you would of gage blocks. After all, they are equivalent in precision. Give them the same care you would to gage blocks. Examine them for nicks and scratches and the scars of rough handling. Incidentally, handle masters as carefully as you would gage blocks or machinists' flats.

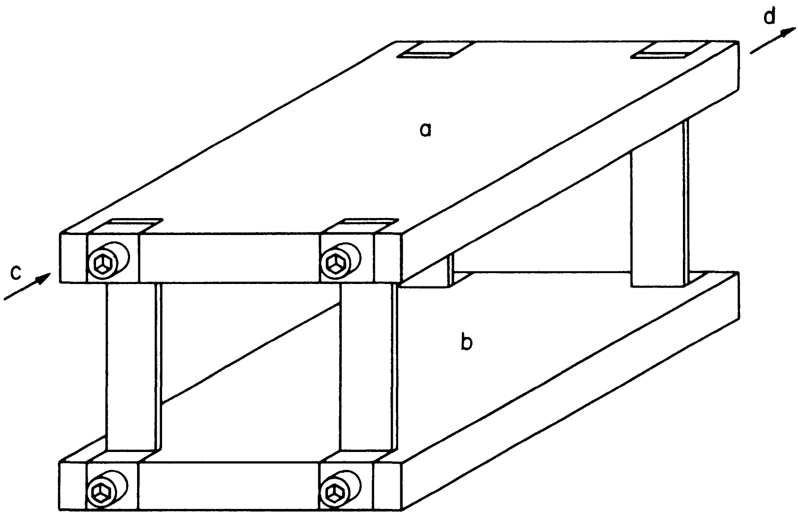


Fig. 57. Basic pantograph mechanism.

Pantograph Mechanisms

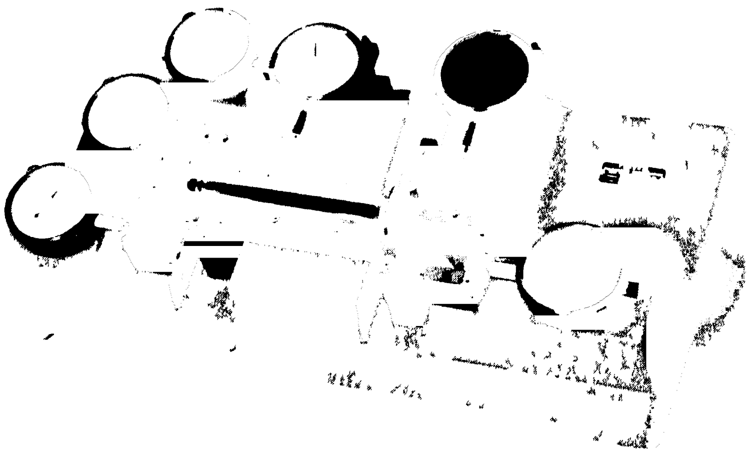
In the field of gaging, a pantograph is essentially a motion transfer mechanism. It consists usually of two parallel steel blocks or plates supported by four parallel strip springs as indicated by the isometric sketch in Fig. 57. Figure 58 shows pantographs in practical use.

The utility of the pantograph is several fold. In the first place, perhaps, it should be considered as a sort of extension of the indicator spindle and point. Its use enables the sensitive contact of the gage to reach into and bear against the workpiece, many times dodging projections or recesses on the workpiece or overcoming measurement conditions in which it would be awkward to manipulate a standard design indicator, indicating gage or comparator. To put this another way, by using pantograph mechanisms the gage's indicators can be offset or

backed off away from the workpiece and the inspector's hands, as he manipulates a pantograph-equipped gage, and thus be more readily readable.

This same attribute makes the pantograph a shock absorber, to a degree, in that the springs of the pantograph help to absorb the blow of lodging a workpiece in the gage, thus protecting the more or less delicate internal mechanism of an indicator.

As has been suggested, the plates of a pantograph, *a* and *b* of Fig. 57, are parallel to each other. They are usually manufactured carefully 4-square with flat, parallel surfaces — made, in other words, with about the same care and tolerances used in manufacturing commercial V-blocks. As can be seen from Fig. 58, one plate of the pantograph is usually fastened



Courtesy of Federal Products Corp

Fig. 58 Pantograph mechanism as used with gaging equipment.

to the body of the gage and then adjustable contact points, lugs and other accessories are fastened to the other plate.

If, for instance, the pressure of a workpiece dimension against a pantograph contact point causes a motion of plate *a* as shown at *c*, Fig. 57, that motion will be exactly transmitted at, say, location *d* and if an indicator point is bearing against surface *d*, the indicator, itself, will register as exactly as if it contacted the workpiece directly. In other words, lateral

motion applied to any part of plate *a*, Fig. 57, is transmitted equally by any and all other parts of plate *a*.

Application of Pantograph-equipped Gage

In using a pantograph-equipped gage, it is sensible, of course, to check the attached contact points and any lugs fastened to the pantograph to be sure they are not loose and that contacts, especially, will bear suitably against the workpiece. (The way the fixed plate is fastened to the gage should also be tested for any looseness of course.) At the same time a check should be made, when the pantograph contact bears against a workpiece or master, to be sure the indicator position is adjusted so that its point presses, with suitable quarter turn indicator tension, against the movable pantograph plate or attached lug.

One other advantage of the pantograph design should be cited. There are, in the strict sense, no movable parts in a pantograph — no pivots, bearings, plungers or gears. All movement is contained in the internal elasticity of the four springs. Hence, there is nothing about a pantograph to get out of order, clogged (within the elastic limits of the strip springs), even though the workpiece is dripping with oil, dust or dirt, or coolant literally pours all over a pantograph. It is necessary only to be sure that the pantograph contact-point gaging surface, the tiny surface of the workpiece under contact, and the area of the pantograph plate or lug under the indicator point are free from grit, chips or grease. Similarly, the solid reference points of these types of gages should be cleaned.

Speaking of the elastic limits of strip springs, however, always check over a pantograph-type gage at regular intervals to be sure one of the pantograph springs has not perhaps been struck or damaged in such a manner as to put a definite, permanent bend or crease in it.

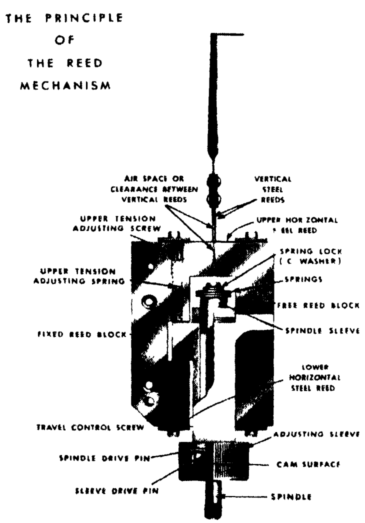
The Reed Mechanism

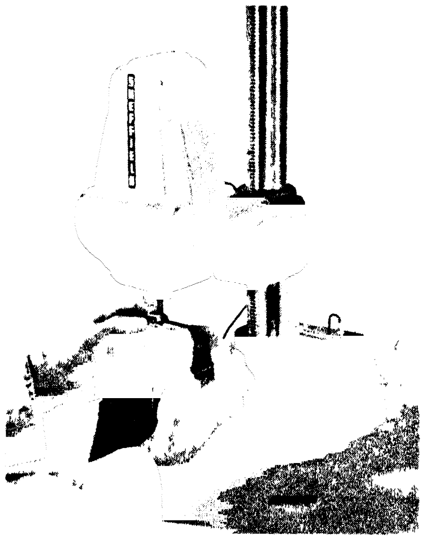
Somewhat allied to the pantograph and yet introducing still other basic principles of measurement, amplification and magnification, is the so-called reed mechanism shown in Fig. 59. Figure 60 illustrates a so-called visual gage, in which a reed mechanism is used.

The reed mechanism consists, essentially, of two metal blocks, one fixed and one floating, joined by steel strips like a

pantograph (the "upper" and "lower" horizontal steel reeds of Fig. 59).

The fixed block is rigidly anchored to the gage head case. The floating block carrying the gaging spindle is connected horizontally to the fixed block by two reeds. A vertical reed is attached at the inside top of each block. There is no contact between them except at their upper ends, which are joined together. Beyond this joint extends a pointer, or target.





Courtesy of Sheffield

Fig. 59. (Left) Basic components of an amplifying reed mechanism.
Fig. 60. (Right) A visual gage which utilizes the reed mechanism of Fig. 59 to amplify measuring-spindle movements.

The gaging spindle is an integral part of the floating block. When spindle and block are moved upward in the gaging operation, the horizontal reeds deflect slightly but the vertical reed on the floating block tends to slip past its companion. However, as these vertical reeds are joined at their upper ends, instead of slipping, the movement causes both reeds to swing through an arc, and as the target is merely an extension of the vertical reeds, it swings through a much wider arc. The amount of target swing is proportional to the distance the floating block is moved, but, of course, is very much greater.

Through a series of lenses, a light beam projects the shadow of the target on the scale of the gage. Thus, mechanical ampli-

fication and optical magnification are combined. Friction is entirely eliminated.

Note that this mechanism incorporates no gears, knife edges or levers — no rubbing contacts of any kind to wear in service or to wear out of adjustment. It is mechanically positive at all times — no back lash — no lag.

Multiple and Special Design Gages

In general, thus far, the study of indicating gages has been confined to single purpose gages and comparators. Gages are made, however, which will measure more than one dimension simultaneously. Almost invariably of course such comparators must be specially designed and constructed for a particular type, at least, of workpiece. They can be made adjustable so as to accommodate variations in sizes of parts but, generally, the parts must be of the same type.

Figure 61 illustrates a few of almost limitless combinations that can be designed for special and multiple measurement.

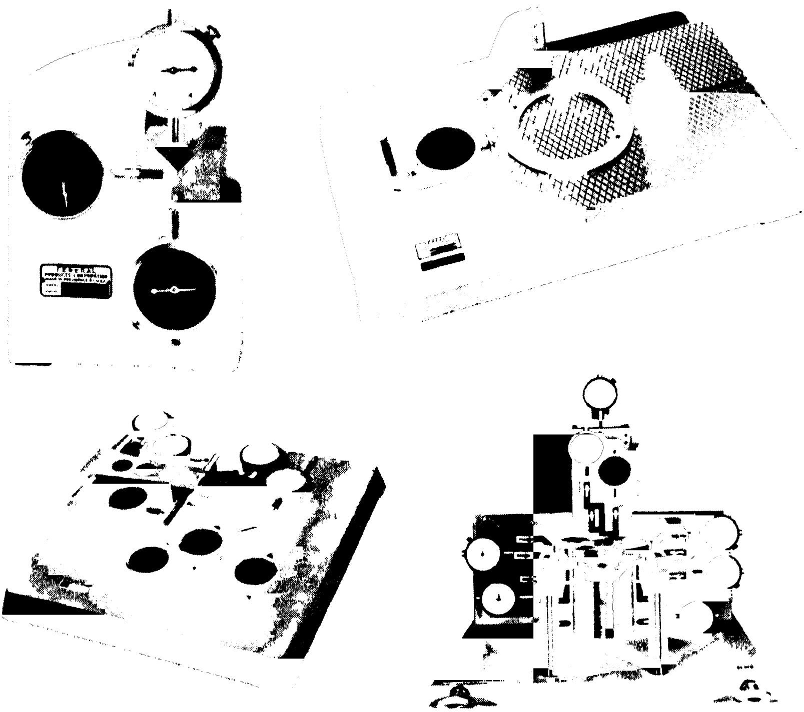


Fig. 61. A few of the many comparators of special design which measure several dimensions simultaneously.

The care, checking, mastering, calibrating and maintenance of special and multiple gages is no different in principle than the supervision of the simplest single-purpose comparator. There are simply "more of the same" as the mother of triplets remarked in regard to the difficulty of bring up a child. Each "station" of a multiple gage is designed to measure a particular dimension or relationship (perhaps such as concentricity) and each station therefore is to receive the same kind of preliminary checks and care the ordinary single-purpose comparator or gage would get. Usually the multi-station master for a multiple gage is made with great care and exactness and the inspector's concern should be extended to make sure that the master is maintained corrosion- and nick-free and that, once the gage has been set, the master is preserved and stored as carefully as any surface plate, for instance, or any other piece of precision measuring equipment.

The main purpose of a multi-station gage is to save time. It is usually designed with spring-loaded contacts, centers, V-blocks, platens and other gage auxiliaries so that the matters of gaging pressures, manipulation, location and even the error of temperature changes are very considerably eliminated. A little special care must be used in mastering the gage — in setting whatever adjustments the gage calls for and in zeroing indicators. Thereafter, workpieces, of course, should not be literally thrown at the gage. Usually the inspector learns after a few trials the quickest and best way to check an intricate workpiece all in one motion and then, more or less automatically, to check a succession of them.

One word of warning should be heeded. Where there are several indicators spaced around a special design gage, the inspector should, in theory, get his nose right over each indicator, in turn, in order to read it accurately. In other words, the error of parallax is a predominant one to avoid in multiple-unit gaging.

Relationships in Measurement

Before getting away from comparators and special indicating gages, the subject of relationships should be reviewed because there are certain relationships which are best determined by indicating equipment. By relationships are meant such phenomena as out-of-round, parallelism, taper and squareness.

The matter of triangle effect or triangular out-of-round, a condition produced on cylindrical work by centerless grinding, has been mentioned before. This relationship is purposely rather grossly exaggerated in Fig. 62. The intent, of course, is to grind the perfect cylinder represented by the dotted circle *a*, but instead the triangle effect represented by the solid lines is obtained.

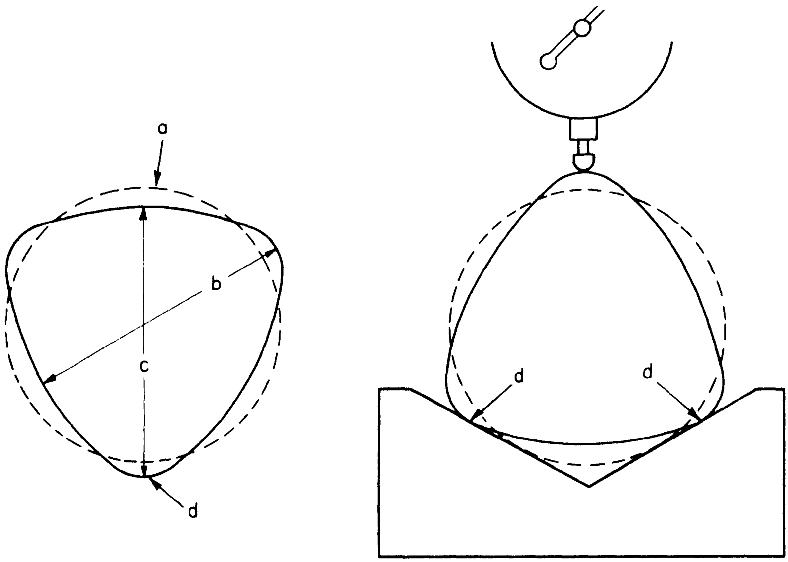


Fig. 62. (Left) Triangle effect produced on cylindrical work by faulty centerless grinding. (Right) Vee-block method of determining the degree of out-of-roundness.

Peculiarly, but true, where triangular out-of-round is present, any diameter measured by simple two point calipering, as with a micrometer, will read the same no matter where around the periphery of the cylinder the diameter measurements are taken. In other words, measurement *b*, Fig. 62, will be the same as *c* or the same across any other axis and the reading may be the same as the diameter of circle *a* — as if the piece were a true cylinder.

But when the piece is rested in a V-block and revolved, the "high points," like *d* and *d*, Fig. 62, "ride up" in the V and, if an indicator is used as shown, the difference between minimum and maximum radii is detected. Although the dimensions represented by diameters *b* and *c*, and the like, will all be the same

when triangle effect is present and while they may well give the same truly cylindrical reading circle *a* would have had, the triangular-shaped shaft will not assemble in a perfectly round hole that is close to the specification diameter of circle *a*, Fig. 62.

While Fig. 62 shows the so-called 60-degree V-block (with a 120-degree included angle), triangle effect can be as readily detected, most usually, in the standard 45-degree V-block. Triangle effect will also appear with 6 or 9 nodes, instead of three, sometimes with 5, 7 or more nodes, but the V-block with an indicator will just about invariably detect it. In a later

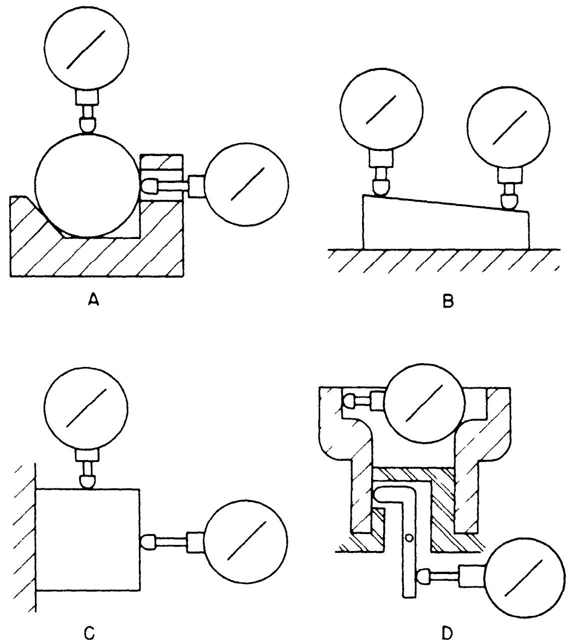


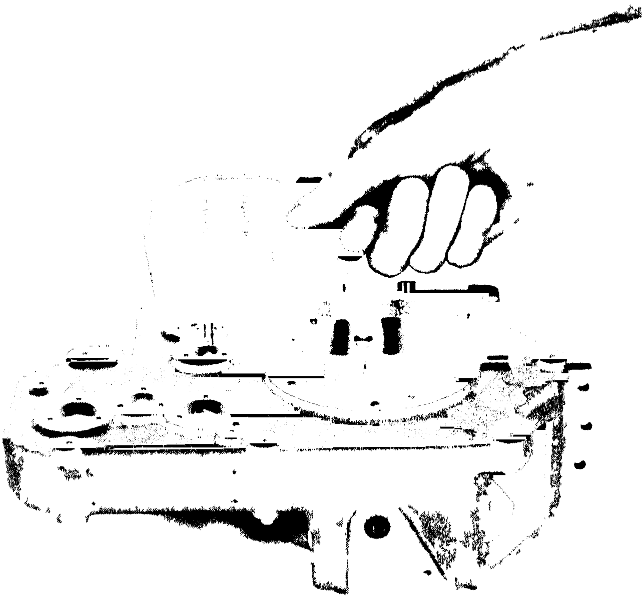
Fig. 63. (A, B, C, D) Conditions of ovality, taper, squareness, and alignment may be analyzed in a single gaging operation by using combinations of indicators in specially designed gages.

chapter the analysis of triangle effect with electronic and air gaging devices is mentioned. Since these measuring devices are more sensitive, they are chosen when any minute amount of triangle effect must be detected.

As for other relationships, Fig. 63 points out diagrammatically how conditions of ovality, taper, squareness and

alignment may be analyzed quickly, with practically a single gaging movement, by using combinations of indicators on special design gages.

If two indicators register through special mounting at 90 degrees on a workpiece as shown in sketch A of Fig. 63, the degree of ovality can be seen at once. Taper likewise can be diagnosed in a single pass by sliding the workpiece on a platen under a pair of indicators as diagrammed at B. Squareness is confirmed by two indicators as at C. Finally, two indicators can quickly point out lack of alignment or concentricity as illustrated in sketch D. Here the cup-shaped workpiece must be held and turned on a fairly close-fitting mandrel of some sort.



Courtesy of Federal Products Corp

Fig. 64. Special indicating gage which measures the error in the center distance of two holes.

Special Indicating Gage Applications

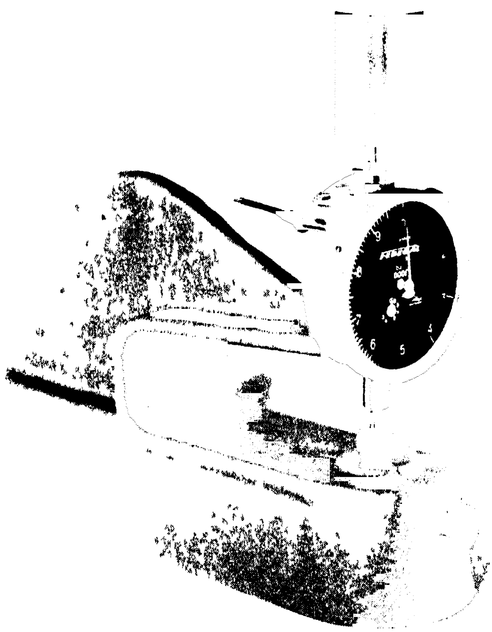
A somewhat unusual use of indicating equipment, where there is sufficient production to warrant it, appears in Fig. 64. The relationship being checked is hole center location. The gage consists essentially of two precision plugs, one of which

is solid to the frame — the reference plug — and the other of which moves laterally — the measuring or locating plug. The movement of the sensitive member registers on the indicator. The gage is, of course, "mastered" on a piece or master whose holes are correctly centered and the indicator is zeroed. As the gage is tried in each workpiece, the indicator hand position away from 0 shows the amount of error in center distance.

Measurement of Soft Materials

Inspection, of course, is not an operation exclusive to metal cutting plants. Inspections are necessary on plastic materials, rubber, paper, textiles, wood and other products. While many things we buy are made of metal, their assemblies often include rubber, cloth, or plastic, and the manufacturer must solve problems in purchasing, producing, inspecting and controlling materials other than steel or brass.

The inspection of articles, components, and sheets of material such as cardboard, felt, and gasket compounds, as well as



Courtesy of Federal Products Corp

Fig. 65. Indicating gage equipped with a weight to provide uniform gaging pressure on soft, easily deformed material.

the materials suggested above, many times involve gaging and measurements. But the gaging of yielding materials — take sponge rubber as an example — demands techniques somewhat different from those already discussed.

For this purpose, gage manufacturers can supply instruments equipped after the fashion of the gage illustrated in Fig. 65. Such gages, as Fig. 65 shows, have their gaging pressure supplied by means of a dead weight riding on the spindle or rack rather than by means of inner tension springs. The size of this weight can be specified to the fraction of an ounce or gram. This type of gage is usually equipped with a lifting lever so that the spindle and the sensitive contact can be raised away from the solid or reference anvil. Both anvils are usually flat and lapped parallel to each other. The standard comparator's spherical point will not do on soft materials because the ball shape so readily deforms the material being tested.

Another factor to be considered in the case of a gage for measuring soft materials is the area of the anvils, particularly the area of the upper or sensitive contact. The effect of the gage on a compressible substance is sketched in Fig. 66. The amount of compression varies not only with the amount of weight bearing down on the spindle but also with the area or cross section of the movable anvil. In many instances the thickness of the material is determined by measuring several layers of it at a time — several thicknesses counteracting the gage pressure more than a single ply — and then dividing the reading by the number of layers to secure an average figure for the thickness of the single sheet.

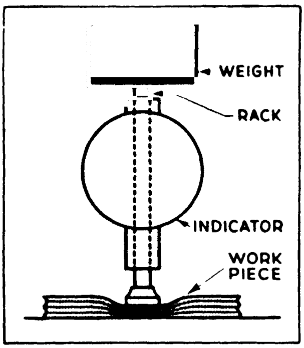


Fig. 66. Effect of gaging pressures on the thickness dimenson of a soft workpiece.

Specifications for this type of gage design and the technique to be employed are usually worked out by a factory's engineering department. Where definite specifications are lacking, and the inspector is faced with the necessity for making a measurement which will indicate the true dimensions of a compressible material, he can be guided by the following suggestions in contriving some suitable apparatus from available equipment.

Gaging Soft Materials Correctly

See that the gaging pressure is as light as possible, but still positive. Provide an upper anvil with an area between one-half square inch and one square inch, the upper anvil to be parallel to the platen.

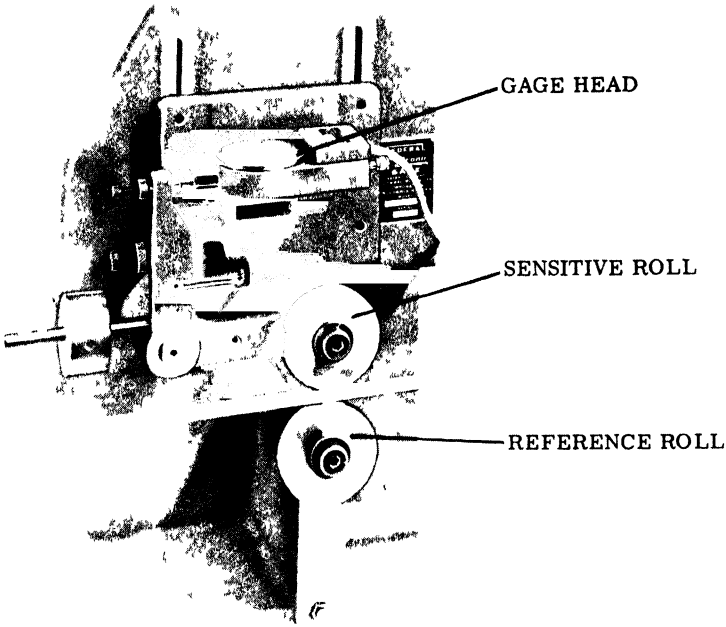
In using such apparatus, the ability to get repeat readings is the objective. Usually, when soft material is gaged, the upper anvil will sink into it a little and the indicator will show some reading. If the gage is left untouched for a few minutes and another reading taken, the second reading will frequently differ from the first one. The upper anvil, in other words, has been imperceptibly sinking into or compressing the material further. If the gage is watched, there will come a time, after a given compression of the material, when the gage reading no longer changes. This is the reading which should be taken, especially if it can be repeated in another similar trial.

This stabilized reading can be obtained more quickly, perhaps, by reducing the amount of weight on the gage spindle or by increasing the anvil area, or both. If repeat readings cannot be obtained, there is probably insufficient gaging pressure. The thickness reading obtained may not be the dimensionally true thickness of the sheet but such readings may be sufficiently accurate, especially when used as comparisons between different sheets, to satisfy the requirements. Another method is to master the gage with a sheet of the material that has been judged to be acceptable by some other test (say at assembly or in the laboratory) and then to compare the sheets to be inspected with this sample or "master."

One other warning. Don't persist in trying to measure or compare what simply can't be measured with the means at hand. If repetition cannot be secured or if the true measurement means nothing when it is secured (because the material becomes too distorted or compressed under gaging pressure), turn to some other technique. Too many times, inspectors solemnly go through measuring operations which are fruitless as far as measurement or control are concerned.

The ideal of course, in connection with compressible materials, is some method of measurement that secures results without actually imposing gaging pressure or even contacting the work. Many times optical means are devised for this purpose. Non-contact gaging systems, so-called, are being de-

veloped, but research and practical commercial applications have not reached a stage where suitable descriptions of such apparatus and techniques can be given at this time. The inspector can obtain information on this subject by application to gage manufacturers for whatever may be available along this line.



Courtesy of Federal Products Corp

Fig. 67. Indicating type of gage which gives continuous measurements of wire diameter while the wire is in motion

Continuous Measurement With Indicating Gages

There are many occasions in inspection work where the gaging and inspection must be performed right at the processing station. Figure 67 shows the type of gage used at a wire insulating machine. The type of measurement illustrated is known as continuous measurement. The production process in many industries — wire, paper, rubber, sheet metal or textile mills and the sheet plastics operations — is continuous right

around the clock. The product is shipped in coils, rolls, rods or sheets — the rolling, the piling of sheets or the bundling of rods also being accomplished very rapidly by automatic machinery. It is commonly difficult for the inspector to get at individual units of such products for visual inspections and gage checks. Certainly it is heresy in modern American mill production to ask for the machinery to be stopped momentarily so that an inspection of the product can be made, hence the type of on-the-job, continuous measuring gages of the general principle illustrated in Fig. 67.

Wherever metal, plastic, rubber and the like is passed through rolls or extruding dies in such continuous processes there are certain principles in connection with gaging the conformance of the product to specifications which the inspector should have firmly in mind.

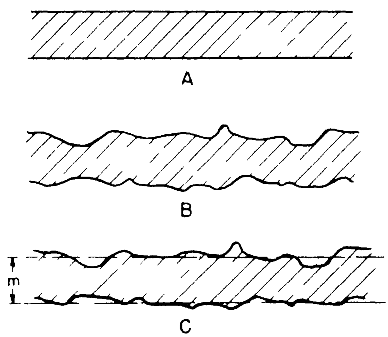


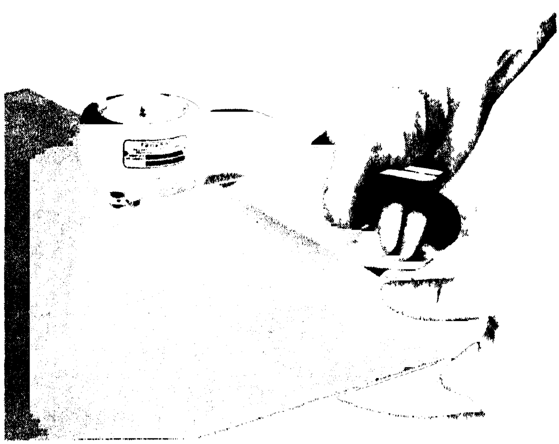
Fig 68. Two types of surface which the measuring contacts of a continuous indicator must measure across, (A) smooth surface, (B) rough surface for which the indicated measurement will be the average value m as shown in (C).

The material rarely leaves the machine with absolutely flat and parallel surfaces as intimated in diagram A of Fig. 68, instead, it contains so-called local bumps, humps, hollows, pits and waves, as shown somewhat exaggerated at B in Fig. 68. Many manufacturers who purchase raw sheet or strip stock to use in their own products find themselves forced to reroll, flatten under hydraulic pressure, grind off, or in some manner redress the surfaces so the stock is more like the ideal of Fig. 68-A before using it.

If the measurement of the stock is made with roller gages like those shown in Fig. 67, the gage's indicators will, of

Courtesy of Federal Products Corp

Fig. 69. One type of indicating gage used for measuring the thickness of short lengths of strip stock



Courtesy of Federal Products Corp

Fig. 70. Another type of indicating gage for measuring the thickness of sheet material.

course, vibrate back and forth sometimes so rapidly as to be practically unreadable unless the indicators are equipped with electrical or mechanical damping devices. In such cases, the measurement obtained is approximately the average thickness of the moving sheet as suggested by dimension m in Fig. 68-C.

Where units — sheets, rods or short lengths of strip — happen to be available for measurement and inspection, a gage like that shown in Fig. 69 is useful or the more precise instrument of Fig. 70. But the same condition of averaging over high spots, low spots, and waves prevails.

If it is necessary to determine by measurement the thinnest section, another principle in gage equipment must be adopted. In the case of insulation coating on electric wire, for example, it may be essential to know how thin the thin spots of insulation are so as to calculate its minimum dielectric or insulating strength if current at high voltage is to be transmitted. There are also situations, especially in assemblies (the thickness of gasket stock for instance), where the maximum thickness must be determined.

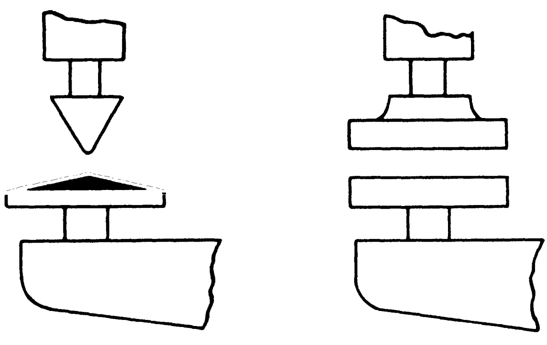


Fig. 71. Gaging contacts of the type shown in (A) will measure the minimum thickness of flat stock. Contacts of the type shown in (B) will measure the maximum thickness of the same stock.

The gaging solution is fairly simple. For thin sections the combination of cone point and a fixed anvil with a small area of flat as in Fig. 71-A will dig down into the hollows. If it is the maximum thickness of stock that is required, the gage anvils should be flat, parallel and wide enough, as in Fig. 71-B, to ride on top of the bumps and the waviness cycle of the stock.

CHAPTER 9

Electrical Gaging Equipment

During the past decade two classes of gages or, better, two systems of measurement, have almost literally crowded into the linear measurement field. One is electrical (including electronic) gaging; the other, air gaging. The subject of air gaging is so important that it will be treated separately in a following chapter.

The development and growth of electrical and electronic gaging apparatus, circuits and systems has been so rapid that the inspector unacquainted with the attributes, uses and applications of electrical gaging is as much behind the times as if he still drove a horse and buggy.

Even more lately, many manufacturing processes and operations have gone "automatic." Automation became suddenly a "household" word. Machines that are electrically operated and electronically controlled are spreading steadily through all factories. Nevertheless, inspection and measurement are still required functions though they, too, are being "electrified" and made automatic with the aid of electronic equipment.

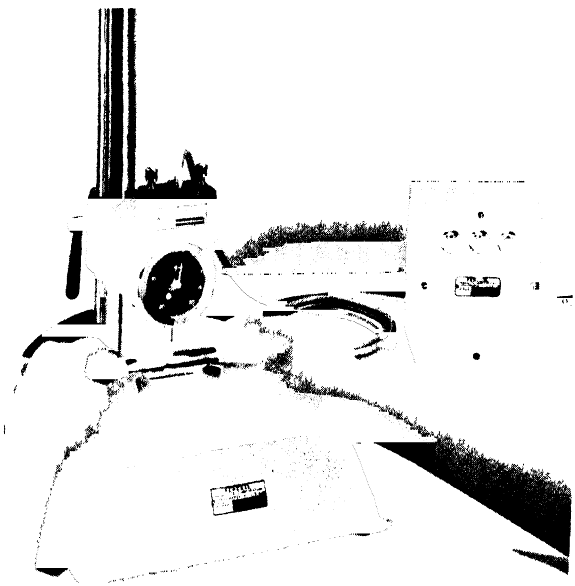
Consequently, the alert inspector will want to be as much conversant with electric and electronic gages — their use, setting, checking and care — as he has been with verniers, micrometers and mechanical indicating gages. Here again the field is so wide and varied and is expanding so rapidly that only its basic principles and conceptions can be touched on in this text. More than ever the inspector will find it necessary to study gage manufacturers' catalogs and instruction books for exact details concerning the proper operation of the particular make of electric gaging equipment he is dealing with.

Today's (and tomorrow's) inspector is liable to find himself using, setting, adjusting or maintaining the simpler electric and electronic comparators. He may be responsible for the

operation of automatic sorting gages which vary in bulk from a unit about as large as a typewriter to a piece of machinery which would fill a living room.

Again, he may be setting and checking machine-control gages on automatic machine operations. These vary in size from a relatively small, automatically-operated caliper gage to a complex system of automatic control gages, measuring I.D's and O.D's, and dimensionally controlling automatic machining operations that stretch several hundred yards along a shop floor.

In the following pages the reader's attention is called to the rather careful distinctions made between *electric* and *electronic* gaging.



Courtesy of Federal Products, Inc

Fig. 1. Single-purpose type electric comparator with signal light limit indicator.

Basic Units of Electric Gaging Equipment

One of the simpler forms of basic electric equipment is illustrated in Fig. 1. It is essentially a dial indicator which can be mounted in the usual fashion on a comparator or gage base. Adjustable microswitches have been assembled in the little

chamber appearing just above the indicator base, switches that are actuated by the motion of the indicator spindle. As the microswitches are closed or opened by the indicator spindle travel they will light the warning bull's-eye lights in the "power box" shown (Fig. 1) electrically connected to the indicator.

The microswitch contacts can be adjusted by the thumbscrews above the indicator in such a manner that when the indicator hand reaches prescribed tolerance limits the pre-set switches close. A yellow light usually signals undersize work and a red light oversize while, frequently, a green light continues shining as long as the work being measured is within specifications.* The electric current can be made to ring a bell or buzz a dial tone in a headset instead of or in addition to lighting a bulb. Blind people have become highly successful inspectors and sorters using such sound equipment where different tones designate Go, Not Go; undersize or oversize work.

The "Electricator"** type of apparatus shown in Fig. 1 is also found on multiple checking gages, on automatic sorting gages and on machine control equipment. Once an Electricator microswitch is closed, the current impulse can be amplified to perform many services the gage designer desires.

The same design principles are also used in multi-purpose gages of the kind shown in Fig. 2 where several dimensions are checked simultaneously on a workpiece. This type of equipment involves a group of measuring contacts complete with microswitches and warning lights. "Multichek"† is one name descriptive of this type of gage. Since, as the illustration shows, the lights are often "patterned" to an outline of the workpiece painted on the light panel, this sort of gage is sometimes referred to as a "picture-panel gage."

The types of gages just described are solely Go — Not Go in operation; the lights only tell when an upper or lower limit has been reached. They have, however, the advantage in use of being speedier than normal indicator gaging. The eye per-

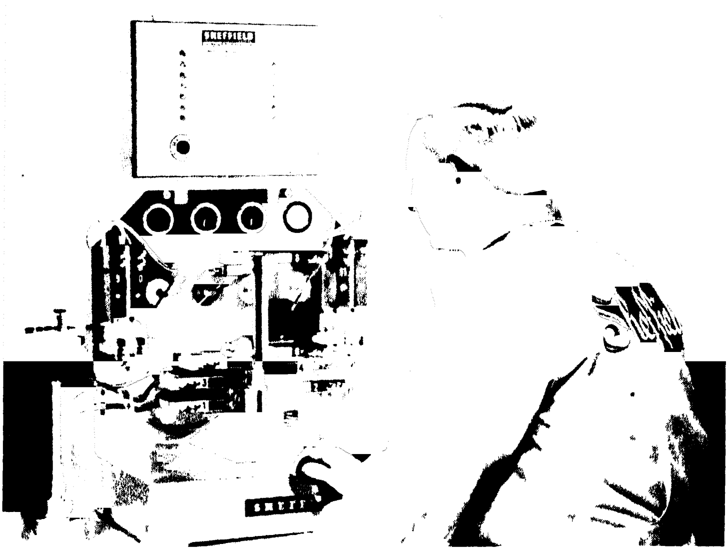
* This color code had not been standardized up to the time of writing (1956). For example, Brown & Sharpe was using *red* for undersize, *blue* for oversize, and *amber* for within tolerance range.

**Trade name, Federal Products Corporation, Providence, R. I.

† Trade name, Sheffield Corporation, Dayton, Ohio.

ceives the lighted bull's-eye much more quickly than it can follow an indicator hand to a certain dial graduation; the human reaction to accepting or rejecting a workpiece is much more rapid under the stimulus of the flash of light.

In setting up such gages for use, first follow the manufacturer's explicit instructions as to adjusting microswitch screws and other suggestions. Other than this, the customary setup precautions previously described for single and multiple mechanical indicator gages are to be followed. The microswitches



Courtesy of Sheffield

Fig. 2. Air-electric multiple-dimension gage with signal light limit indicator. Thirteen different dimensions are being gaged simultaneously. No signal light indicates dimensions is within tolerance; a green light indicates dimension is undersize; and red, oversize.

and all the electric apparatus in this type of gage are designed and made to allow an error in measurement not exceeding 5 millionths of an inch. Hence, if such a gage is not accurate in action, look to mechanical causes.

If, however, the warning lights or signals fail to function and if the mechanical action of the gage has been thoroughly checked, the services of an electrician or someone skilled as a radio repairman may be required. However, embarrassment may be saved by being sure, first, that the electric gage has been

plugged into a live factory circuit. Peculiarly, many service calls on electric gages end up with the report that the gage was receiving no electricity! Electric gages are designed so that only a milliampere or so of current goes through the switch contacts (or sparking is dampened with condensers) and most of them will operate at least a thousand hours before a contact corrodes or a tube wears out. On the other hand, dust, dirt, coolant, oil, and moisture can creep inside and switch points and connections may have to be cleaned free of these enemies of electric conductivity.

The Electronic Comparator

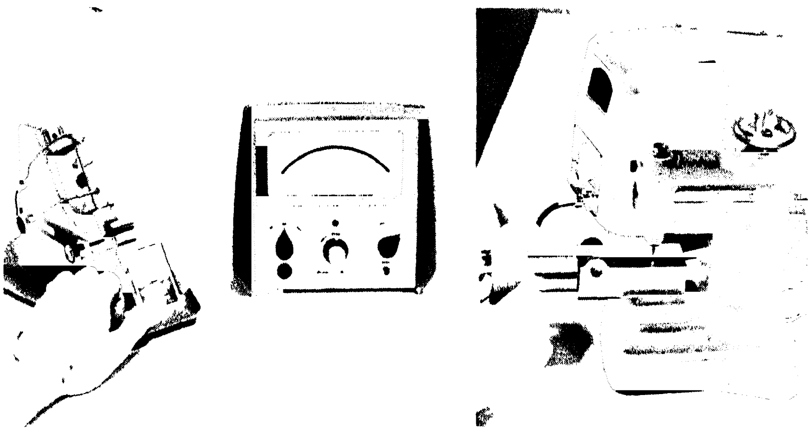
The history of precision measurement displays many types of instruments and devices with a variety of discriminations or accuracies. Back in colonial days, Vernier added his invention to the steel rule, capable of measuring as close perhaps as 1/64 inch or 1/100 inch, and gave artisans and mechanics an instrument that would detect a size difference of 1/1000 inch. Something like a century later the micrometer was invented which brought us measuring precision in terms of 1/10,000 inch.

Within another half-century Johansson put his label on the "Jo" block which, while it gave us a measuring standard varying only two or three millionths of an inch from the actual, could not be handled consistently without a probable error in manipulation ranging as high as 50 millionths. Even mechanical dial indicators, developed soon after Johansson's invention, cannot ordinarily be trusted to accurately detect size differences of less than 50 millionths (.000050 inch). In the meantime too, progress had been made with interferometry and the optical flat (described in Chapter 11) with its resulting discrimination of .000012 inch.

With the advent of the electronic comparator — so-called because of its accompanying electronic circuits and devices we are able to read a size difference of one millionth of an inch (.000001 inch) on a dial or meter scale.

In these more modern gages, electricity is successfully employed to transform the motion of a sensitive or measuring contact to a readable, accurate figure. Some electronic gages make use of the increase or decrease in reactance when a plunger actuated by the measuring contact moves in and out

of an energized solenoid. In another type, the spindle motion changes the positions of high frequency coils in relation to each other. Others make use of a change in capacitance and still another is based on unbalancing a Wheatstone Bridge circuit. In any case, the electrical change caused by any movement, minute as it may be, of the measuring contact is picked up and amplified by a circuit somewhat resembling those used in radios and then converted to visible readings on a dial.



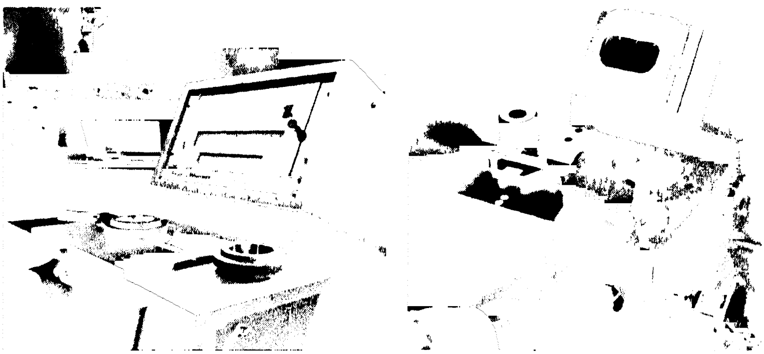
Courtesy of Federal Products, Inc *Courtesy of Brown & Sharpe Mfg Co*

Fig. 3. (Left) Commercial type of electronic comparator being used to measure external diameters. (Right) Another electronic comparator with a special adaptor for gaging internal diameters.

Advantages of Electric and Electronic Comparators

It has been suggested, previously, that indicating comparators of the mechanical type have a discrimination in measurement down to .0001 inch, special designs being obtainable that will measure to .00005 inch. Electric comparators have comparable discrimination. It is the field of measurement in which tolerances are below .0001 inch that the electronic comparator particularly fills, although it is a perfectly satisfactory instrument for use on work in which tolerances exceed a tenth of a thousandth. No other instrument so satisfactorily, quickly and easily handles measurements where the specifications are for .0001 inch tolerance or less. Accuracies to .00001 inch or to microinches, .000005 inch (and even .000001 inch) can be obtained.

In addition to superior accuracy, the electronic comparator possesses two other favorable characteristics. It is faster than the usual mechanical indicating gage; the electric meter flashes the correct reading faster than the hand can adequately or correctly manipulate the workpiece and faster than the eye can comprehend the signal. The other property is the lack of wear. True, there are moving parts in connection with the sensitive contact or spindle, but the manufacturer of electronic gages is able to so design the mechanical moving parts and the electric relationships in the head of the instrument that no appreciable error is detected from what might be called the use or wear of the instrument. Gear trains, bearings, bushings and the like in mechanical type indicators do wear, of course, and an equivalent instrument error is then noticed.



Courtesy of Federal Products Corp

Courtesy of Colt Industries, Pratt & Whitney Machine Tool Div

Fig. 4. (Left) An extra precise electronic gage or measuring machine. (Right) Close-up view showing zero comparator reading being checked with a gage block set-up.

In addition to the types of electronic comparators appearing in Fig. 3, the gaging industry also furnishes extra sensitive, extra accurate "gaging machines," so-called, for outside diameter, length, and particularly for superaccurate inside diameter measurement. Two of these are shown in Fig. 4.

Needless to say, apparatus of this kind is costly. It is seldom found anywhere in the shop itself but in the temperature controlled, air conditioned gage laboratory. Furthermore, although such gaging machines are designed and built to detect a size difference of .000001 inch, the inspector, unless he is specially instructed and practiced, may find it difficult to achieve an

accurate reading precisely to a millionth of an inch — a micro-inch. An inspector assigned to using a measuring machine should, if at all possible, be instructed by the manufacturer of the equipment in its exact use.

Precautions in Using Electronic Comparators

Because electronic gages are capable of measuring to .000005 inch, the inspector must display extreme care in manipulating masters and workpieces on the solid reference anvil and under the sensitive contact. It takes mighty little "cramping" of the part being measured, only a miniscule of mishandling, to produce a .000005-inch error in measurement. In fact, the electronic instrument so readily amplifies and magnifies minute dimensional variations that even an otherwise experienced inspector using it for the first time will frequently claim the instrument is inaccurate. Many an inspector and mechanic, when starting to use electronic gages, has come to realize for the first time his habitual carelessness and ignorance in the manner of holding and manipulating workpieces and gages.

More than usual precautions must be observed in making ready to measure with an electric comparator. Make sure the instrument is not exposed to direct sunlight, steam radiators, open doors or windows or other forms of draft, nor to excess vibration. The reference anvil should be frequently checked for flatness, scratches, nicks and corrosion. The solid reference anvil and the clamping device for the adjustable head must be tight. The real meaning of instrument looseness, deflection, and the effect of uncontrolled temperature changes becomes evident when sensitive electronic equipment is used.

The standards of cleanliness applied to the reference anvil and essential parts of an electric comparator are the same as that applying to gage blocks.

Most electric and electronic gages are designed and built to measure accurately at some standard voltage, usually 110 volts. If, after an electric or electronic gage has been mastered, after its zero and tolerance limits for the particular work at hand have been established, the supply line voltage should drop more than 10 per cent (1 or 2 volts), or surge up a volt or two, the gage should be remastered. An electric or electronic gage which has been set at 110 volts, may show an appreciable error if the voltage drops to 105.

Figure 60 in Chapter 8 shows the reed type instrument, which employs an electric bulb — with mirrors or prisms to flash the reed movement onto a scale — and is frequently referred to as an electric gage. It must not be confused with the electric gage, or electronic gage, defined above, however, which employs electricity directly, and not merely an electric light beam, for amplification or magnification.

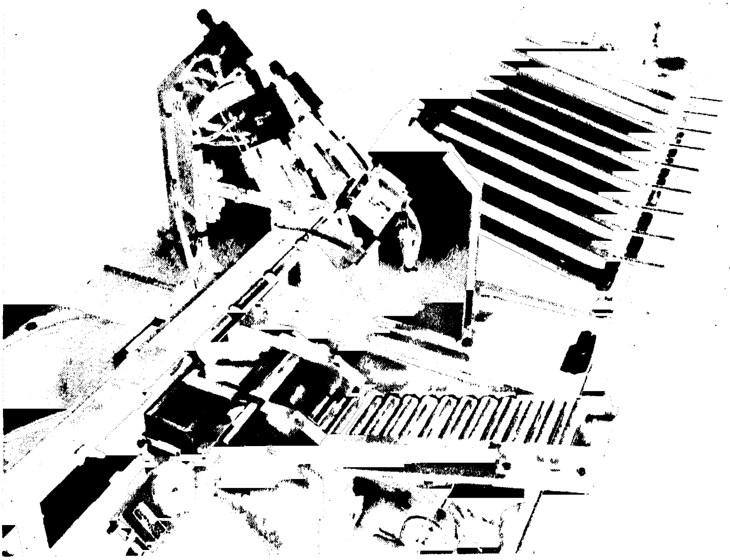


Fig. 5. Automatic electronic sorting gage being used to classify wrist pins by .0001-inch increments.

Automatic Sorting Gages: Economics

In certain operations, especially on small parts in screw machines and presses, it is sometimes found less costly over-all to maintain fairly good control over quality, but to allow the quantity of rejects to run as high as 5 or 10 per cent and then to screen out the defectives with an automatic sorting gage. Such a plan, under certain conditions, will make the final cost of the machined components lower than their cost would be if an attempt is made to hold the rejects and scrap at each machine down to 1 per cent or less. In the latter case, machine down time and the extra inspection force required to check or screen the work sometimes make the piece cost higher.

Hence, plain manufacturing costs and economics often recommend the introduction of automatic sorting gages in place of line or patrol inspections and consequently the inspector finds himself charged with the responsibility of setting and checking an automatic sorting gage and overseeing its operation.

Another factor of plain economics brings about the use of automatic gaging. The production of the familiar automobile engine wrist pin offers a concrete example. One way is to set and constantly police a grinder, and to have an inspector con-

Courtesy of Sheffield

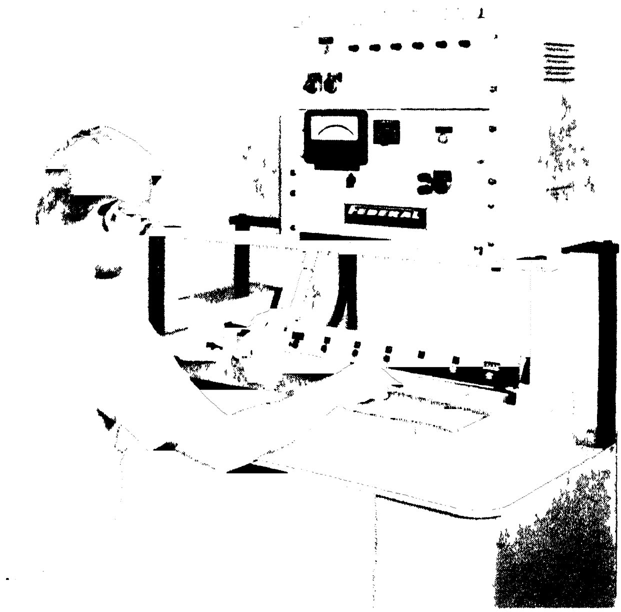
Fig. 6 An automatic electronic gage capable of sorting and marking pistons classified as to wrist-pin hole sizes

stantly checking its output, so that each wrist pin is within a tolerance of .0002 inch — practical duplicates of each other. This method requires an operator on each grinder and considerable machine "down time," plus several inspectors checking a battery of grinders.

The more modern way is to widen each grinder tolerance to, say, .002 inch and then have the output from the line of grinders put through an automatic sorting gage of the type pictured in Fig. 5. Here the pins are automatically sorted into size classi-

fications .0001 inch apart and marked. This method reduces down time at each grinding machine and usually allows an operator to take care of several grinders instead of one — not to mention a reduction of inspection time and expense.

The holes in the corresponding pistons are bored under similar wider tolerance conditions and are similarly size-classified, as shown in Fig. 6, and marked. At assembly, a certain size pin is assembled into piston holes of the same size classification. This results in even closer fits than under the older



Courtesy of Federal Products, Inc

Fig. 7. An inspection operation which combines manual. visual inspection with automatic size gaging and sorting of typewriter parts.

method, greater engine life and a quieter automobile. The method described is generally known as selective assembly. Substantial cost savings are effected not only at machining operations but also at assembly. Sorting and selective assembly is practically a must in the ball bearing industry, for instance, because of the extremely close assembly tolerances required.

The third type of economy acquired through the use of automatic electric sorting gages comes from those situations where, for a number of good reasons, parts or components

must be gaged and inspected 100 per cent and where it has been the practice to accomplish the screening through squads of inspectors doing the work manually (See Fig. 1 in Chapter 18). Sometimes a visual inspection is required along with the piece-by-piece manual gaging.

Under such conditions, substantial savings in time and effort are made by introducing automatic sorting gages. Depending on the nature of the product or component to be screened by automatic gaging, the gage may replace the effort of a number of 100 per cent inspectors, freeing them for other and more valuable work in the plant. An automatic gage can do the work, in many circumstances, of a dozen or more inspectors and get the job done more quickly and more accurately.

Figure 7 pictures an automatic sorting gage performing, in a sense, a dual operation. Here the single operator is performing a 100 per cent visual inspection for burrs and defects on typewriter bars and at the same time feeding them into the automatic gage which makes the essential measurements, sorts the bars into specified classified sizes and rejects those which are oversize and undersize.

Automatic Sorting Gages: Installation, Setting, Care and Checking

Pieces of equipment of the size, intricacy and cost of automatic electronic sorting gages are often, if not usually, selected, bought and installed without the Inspection Department being consulted or notified. Such proceedings are generally assigned to Engineering. But, just as often and in fact, usually, the routine daily setting, checking and care of such equipment, after it is installed, becomes in a short while, by a normal process of industrial delegation, the responsibility of Inspection.

To repeat a previous suggestion or warning, the inspector should first make himself thoroughly conversant with the gage manufacturer's instruction books and catalog material, pertaining to the particular automatic sorting gage, for detailed information concerning how to set, adjust, check and maintain the gaging machine.

The inspector can and should back up the gage manufacturer's instructions with his own fundamental knowledge of gaging principles. After all, the primary function of the

electric-electronic automatic sorting gage is correct measurement. Setting, checking, verifying the accuracy of this function on an automatic gage is essentially no different than for any hand or bench gage.

For example, Fig. 8 offers a close-up of the measuring contacts of the wrist pin gage spoken of just previously and pictured in Fig. 5. The gaging machine's conveying mechanism automatically feeds successive wrist pins to the measuring contacts and carries them on by. One pair of measuring contacts checks

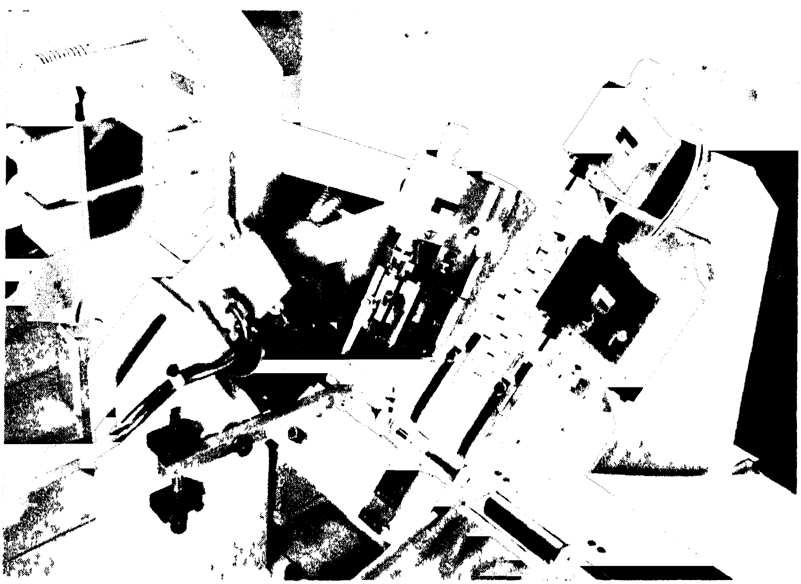


Fig. 8. Close-up view of wrist-pin measuring contacts for sorting machine shown in Fig. 5.

diameter and out-of-round. (A special device revolves the wrist pins under the measuring contacts at this point.) The next pair of measuring contacts checks taper.

Thus, it might be said that the gaging machine substitutes for a pair of hands in that it "feeds" the pieces in under the contacts and revolves them, holds them down to the reference surface or platen and prevents the workpieces from tipping or producing any manipulation errors, in much the same fashion an inspector would work were he manually checking such work under a bench comparator. Hence, in setting, mastering, check-

ing and maintaining an automatic sorting gage, the inspector treats each measuring unit much as if he were dealing with individual bench comparators.

Periodically or at every reasonable opportunity the inspector should check the platens for roughness, scratches, wear and particularly for dirt. Similarly, the movable or sensitive contacts would be examined with a close watch being kept for flat spots or undue distortion of the contact profiles from wear. The gaging pressure a movable contact exerts on a workpiece can be adjusted — be sure it is correct for the purpose. Be sure adjusting screws and other parts are tight; looseness may spoil the gage's accuracy and repetition. Follow closely any other instructions the gage manufacturer may offer.

With the gage in operation observe the way the pieces are "feeding" through the measuring stations to be sure the conveying mechanisms are not in any manner cramping or misaligning the workpieces or otherwise creating inaccurate readings. The gaging machine should be free from undue vibration, thumping or jarring (such as may result from nearby machinery) which could interfere with its precise measuring function. The workpieces should be clean — so free from grit, oil or coolant that such foreign material does not interfere with getting a correct measurement nor wear the gage contacts.

In most cases where an automatic sorting gage is in use, the inspector would provide himself with a separate hand gage or bench comparator whose accuracy and discrimination are equal to or better than the rated discrimination of the automatic gage. With such equipment he can periodically check the output of the automatic gage and either assure himself of its continued accurate operation or get a warning that something may be amiss in the automatic gage's measuring function. For instance, in checking the wrist pin gage, Fig. 5, the inspector would make independent checks on sample workpieces from each size classification chute, in this way not only verifying the measurement accuracy of the gage but also making sure the electronic classifier equipment is functioning properly.

Machine-Control Gages

One of the forerunners of the present-day automatic machine-control gage is the type of indicating caliper gage shown in Fig. 9. The gage is swung down on to the workpiece, after

the latter is centered or chucked and the machining action started, and the gage's caliper is engaged on the O.D. The gage (except in the case of plunge grinding) traverses the work with the cutting action and its indicator shows the amount of metal being removed at each traverse. The machine operator watches the indicator which tells him when the work has reached specified size.

Where such gages are in use, the amount of inspection required on the work put out is very materially reduced if not practically eliminated. However, it is wise to have an inspector

Courtesy of Brown & Sharpe Mfg Co *Courtesy of Federal Products Inc*

Fig. 9. (Left) An electronic caliper gage for hand operation. (Right) Electronic caliper gage which measures as the work piece is being machined.

check the work at the start of a run and occasionally thereafter to be sure that the machine operator is reading the indicator correctly and also that the operator, through neglecting the finish size, is not getting oversize work from stopping the machining too soon or putting out undersize work from not acting quickly enough.

A gage, and its indicator, like that pictured in Fig. 9 can be originally set or "mastered" to correct finish work size with a disc master or the equivalent in the same manner any indicating caliper type comparator gage is mastered. The general practice, however, is to machine the first workpiece, checking its diameter from time to time with a separate hand gage, until

it is at specified finish size. With this workpiece still revolving, but without any cutting action taking place, the machine caliper gage's indicator is set to finish size. Thereafter, each successive workpiece is machined until the indicator signals its finish size. Finished workpieces are checked periodically and independently with a separate hand gage, as suggested above, not only to verify work size but also to determine whether the caliper gage contacts are wearing back unduly.

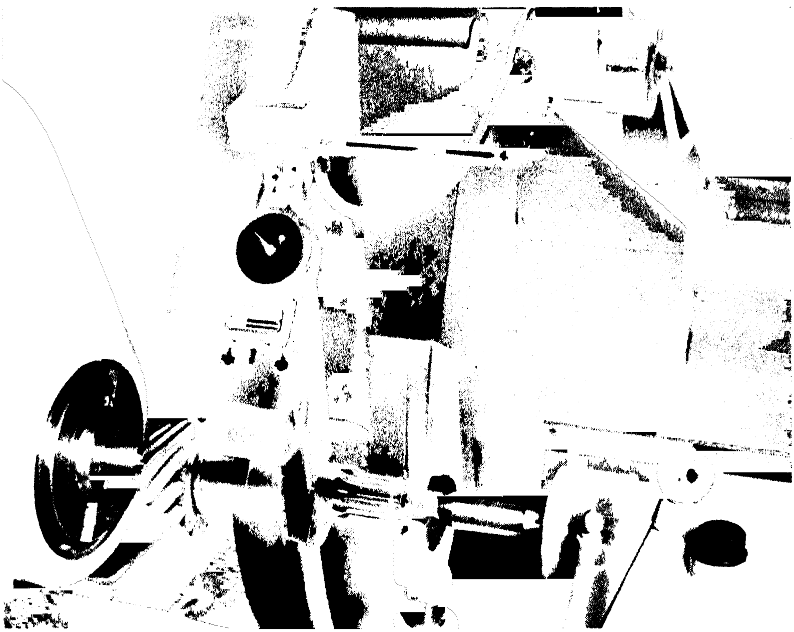


Fig 10 This electric caliper gage not only indicates but also controls the machine operation through the attached microswitch

Electric Attachments for Machine Control Gages

Another step in "automation" progress, in so far as the contribution of gaging is concerned, has been that of adding the microswitches of the "Electricator" type of indicator to the indicating caliper gage previously described. An example of this sort of equipment is shown in Fig. 10. The size-limit electrical impulses from this equipment are used to light warning lights or, through amplification, to stop the machine at the proper time or control the machine feed mechanisms.

Figure 11 pictures another step in machine control gaging where the caliper on the revolving work transmits size signals through air-electric apparatus to control the operation of the machine and the finish size of the work.

Oftentimes the gage system is an integral part of the machine, designed specially for it and built into it. In Fig. 12 you see a practically completely automatic machine which loads itself, chucks and unchucks the work automatically and machines it. The gage, just at the left of the chuck, takes over the finish-size control function.

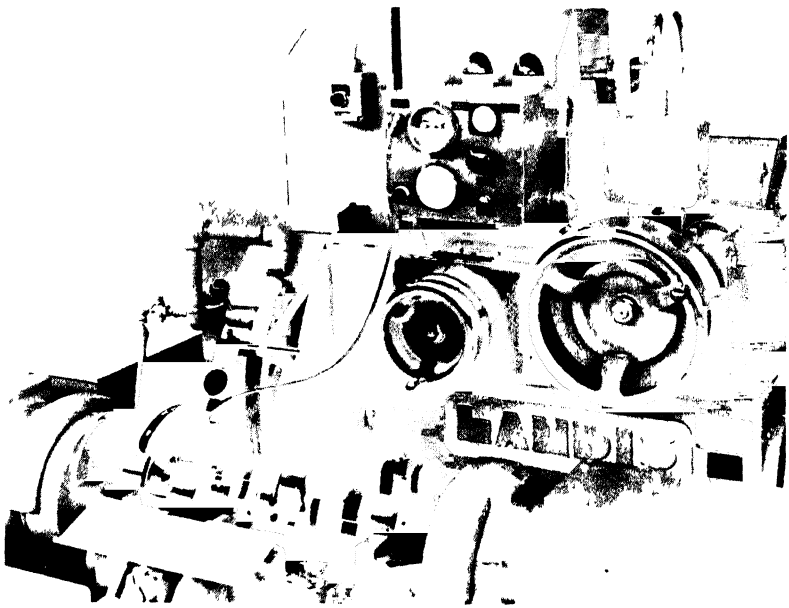


Fig. 11. A combination air-electric gage which operates to control the machine operation and the finish size of the work.

Although a great deal of ingenuity has been displayed in the creation of such machining automatons, a certain amount of independent inspection is still valuable. By periodically checking samples of the work produced, including a piece or two as each job is set up and starts off, the accuracy of the setup and the continuation of that accuracy can be verified. Only under the impossible combination of perfect men using perfect machines on perfect material would consistently uniform and precise work be produced hour after hour.

Additional Precautions to Observe with Automatic Gages

On the more or less fully automatic machine, represented by the equipment pictured in Fig. 12, where the workpieces are loaded, machined and unloaded automatically, the caliper gage is moved out of the way, also automatically by solenoid or air cylinder mechanisms, during the unloading cycle. After the new workpiece has been automatically loaded and machining starts, the same solenoid or air cylinder mechanisms set the

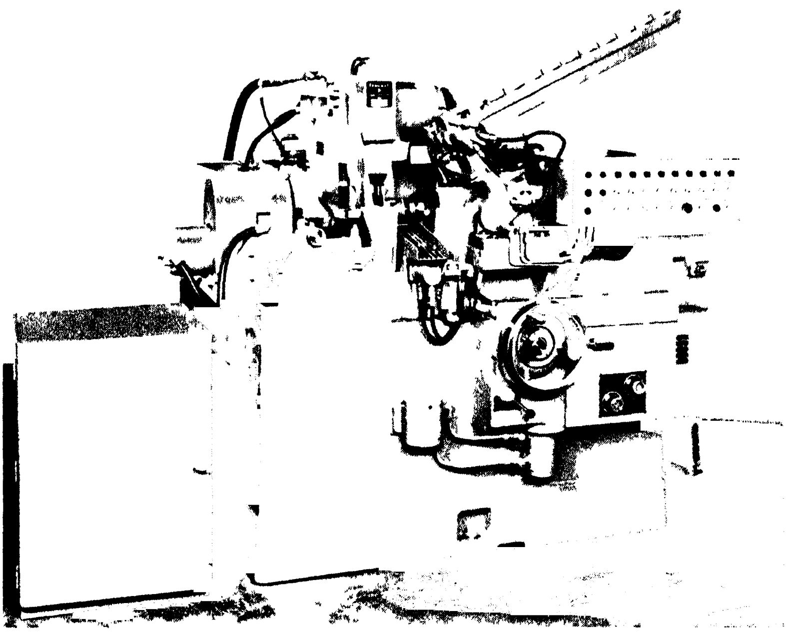


Fig 12 A fully automatic machine with automatic loading and machining size controlled by electronic gaging.

caliper on the work, automatically, in measuring positions. When the work is at specified size, the gage signals the retract-unload-load cycle to start.

Like anything subject to friction, pressure, dirt, and wear, the gage actuating mechanism can fail, until corrected, to place the caliper on and over the workpiece in proper alignment. If the machine is failing to produce work to specified size, in other words, the inspector should look to the gage handling appa-

ratus, as a possible source of trouble, in addition to the customary search for looseness, binding or wear in the caliper itself or for error in setup or mastering. Sometimes in a similar manner, the machine's automatic loading mechanism, due to chips, dirt, friction, or wear, may fail to "set" the workpiece correctly for machining and create a condition where it is impossible for the machine to bring the work to size.

Since the inspector is often charged with the responsibility not only for detecting off-size work but also for analyzing the causes, in connection with the use of electric automatic sorting gages and machine control gages, two suggestions in review are appropriate here.

Between the gage manufacturer's directions and his own knowledge of gaging fundamentals, the inspector should be able to search out any inaccuracies caused by the gage parts themselves — looseness, wear, binding, misalignment, etc., in the calipering contacts and immediate connecting mechanisms. But, as has been intimated, the trouble may come from the material or gage *handling* apparatus which can "spoil" a precise measurement just as readily as an awkward novice trying to measure with a precision bench comparator.

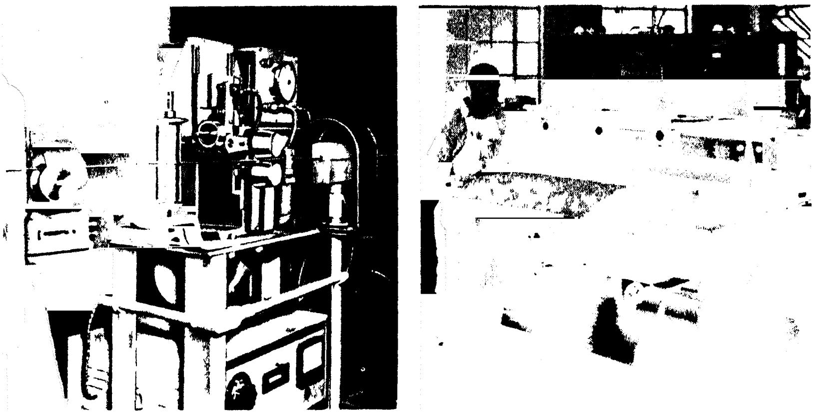
Occasionally the trouble is electric or electronic. The gage mechanism itself senses the measurement accurately but the electric signal or impulse necessary for correct automatic sorting or machine control may be transmitted incorrectly or not at all. The trouble may be from fouling of switch contacts, from a burnt-out tube, resistor, relay or condenser, or from a loose connection. Or the electrical system may not have been correctly "hooked up" in the first place in accordance with the proper circuitry.

Another source of difficulty, at first seemingly obscure, may arise in the particular case of automatic machining, where the machine itself may not be able to respond fast enough or accurately enough to the control signal the gage supplies. Or the trouble may be as simple as the need for sharpening the cutting tools or dressing the wheel.

When an automatic sorter or an automatic machine fails to produce work to tolerances, the tendency is first to blame the gaging mechanism when the difficulty may actually have its sources in any number of other everyday mechanical or electrical causes.

Post-process Gaging

The general type of calipering gages used in automatic machining, like those illustrated in the preceding few paragraphs, are sometimes described as "in-process" gages because they control, or at least measure, while the work is being machined. Other types, which are just as fundamentally in-process gages, are continuous measuring gages, like the examples pictured in Fig. 13, which measure and control wire diameter, insulation, strip or sheet thickness, and the like, while the process is going on. One of the limitations of in-process gaging is that it controls random-size deviation only



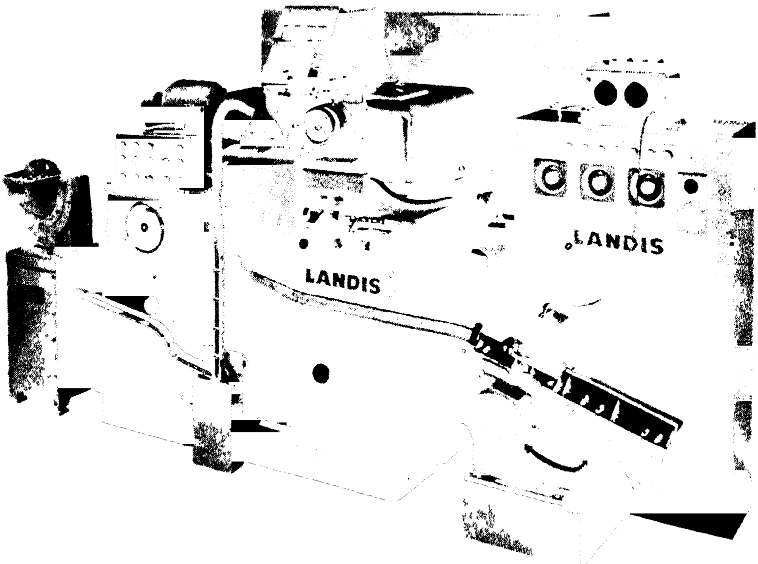
Courtesy of Federal Products, Inc

Fig. 13. Two types of electronic gaging for continuous manufacturing operations. (Left) The gage here is continuously measuring insulation thickness and controlling its application. (Right) Plastic sheet thickness is being gaged continuously and the rolling process automatically controlled.

and cannot compensate for cumulative deviation or machine drift. Even a machine in good condition will drift; that is, it will produce work gradually changing in size as it gathers the heat generated by machining as well as the heat of its own operation. To correct this, "post-process" gaging is employed.

The basic conception in post-process gaging is to have an automatic gage which will measure each piece immediately *after* it is fully produced. The effect is similar to the arrangement where an inspector or the operator checks each piece produced with a hand gage or bench comparator. It has the

advantage over in-process gaging in that it can be performed under more favorable conditions, free from coolant splash, heat, and machine vibration. A post-process gage can be designed to flash simply a warning light, when off-size pieces appear or, like other automatic gages, it can have control equipment to stop the machine or change the tool or wheel setting automatically.



Courtesy of Federal Products, Inc

Fig. 14. One type of post-process gaging set-up used for automatic size control and screening.

Figure 14 pictures one such installation where each finished part slides down a chute directly from the machining area to a post-process gage. The gage is essentially a condensed version of an automatic sorting gage (see Fig. 5 and accompanying description) which checks the part and then directs it into the proper disposal chute for those which are undersize, oversize or acceptable. At the same time the gage transmits a signal to the machine if the workpiece is out-of-tolerance.

Another development in the field of automatic size control on fully automatic machining operations has been the installation of both in-process and post-process gaging equipment on

a machine. The in-process gage exercises close control over random deviations and the post-process gage controls machine drift. When correction for drift is necessary, the post-process gage does not control the machine directly but signals its partner, the in-process gage and the latter in turn adjusts itself or automatically compensates in its own setting to eliminate the size deviation and signals the machine also what to do to compensate.

Several advantages accrue from the partnership mentioned above. One is a final output of at least 99.9 per cent perfect, in-tolerance work. Another advantage is the ability of the partnership to control an older, worn machine with minimum machine down time.

If an automatic machine is not sensitive enough, if it cannot respond quickly enough to an in-process control gage signal, the delayed action will permit the production of off-size work. And if the gage control is the type that shuts a machine down entirely, until an operator can make the tooling adjustments, the machine may be stopped over too high a percentage of productive time. The post-process gage partner offsets such disadvantages because, in addition to signalling the appearance of off-size work, it automatically screens out the few scrap or oversize pieces which may appear while the machine is either automatically correcting itself or is being corrected by an operator.

Often also, a post-process gage is equipped with an electric time delay feature. The time delay can be manually set or regulated to delay (or hasten) the shutdown or control signal to the machine. Usually the time setting is based on deliberately allowing a small percentage of off-size pieces to be made. In many circumstances, permitting a post-process gage to screen out a prescribed amount of scrap is less costly, over-all, than to have the machine's production continually shut down or delayed, for size adjustment.

For the inspector, the checking, setting, mastering and maintenance of a post-process gage involves the same fundamental activities that have been described previously for other automatic electric gages.

CHAPTER 10

Air Gaging Equipment

While the ideas and principles of fluid and pneumatic methods of making measurements were known and applied more than a century ago, their outgrowth, now known as air gaging, failed to get much specific development until after World War II. Now the use of compressed air as a basic means of sensing and securing precision measurements is commonly accepted and widespread in industry. Along with the adoption of air gaging, however, too few have taken the trouble to study some of the underlying principles of air gaging and especially to appreciate the advantages, as well as the few shortcomings, of air gage applications and equipment.

Air gages are used to measure outside diameters, being equal to other types of portable and bench comparators in many respects. Air gage equipment also is being used to check relationships like concentricity, squareness and flatness. But the air gage's great popularity is undoubtedly due to its unique aptitude for measuring hole and bore conditions. In many applications an air gage is superior to other types of internal gages. Examples of the use of air gaging will be brought out farther on.

Basic Elements of the Air Gage

The principles on which the air gage is based will be gone into in some detail because if these are clearly understood, the inspector can then get the most use and the greatest accuracy out of an air gage and will realize more readily when or why it is not performing as it should.

All air gages require a reasonably steady source of compressed air. It may be taken, usually through a reducing valve, from a factory air line or it may come from a separate, special air compressor. Air gages require from about 30 to 80 pounds

per square inch pressure and the air supply should be filtered or cleared in some manner so that it is free of dirt, grit, oil and excess moisture. (A section farther on describes the maintenance of air gages and offers a few suggestions for getting clean, steady air to them.)

To understand the principle of air gage action, refer to the schematic diagram in Fig. 1. The compressed air first goes through a so-called master jet, which is essentially an orifice or hole with a precisely controlled inside diameter, placed in the line of flow. The master jet imposes a decided restriction

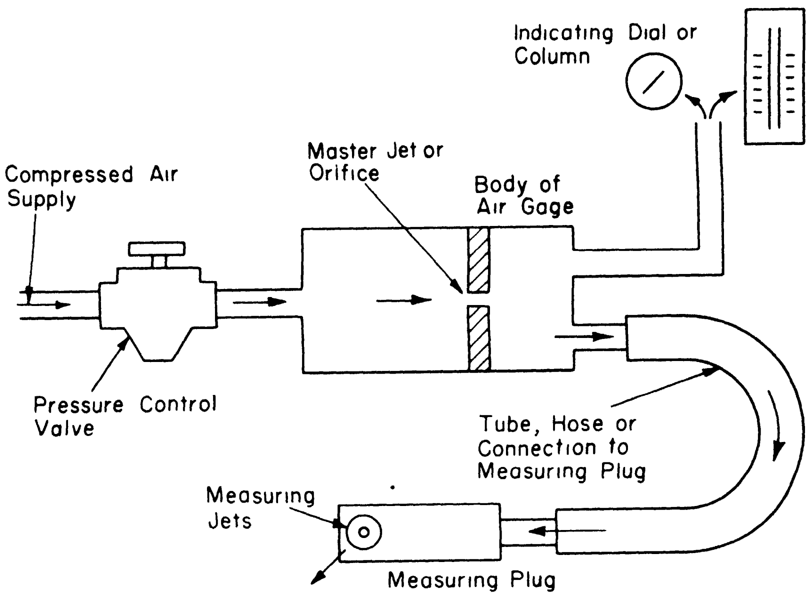


Fig. 1. Schematic diagram showing the basic elements of an air gage.

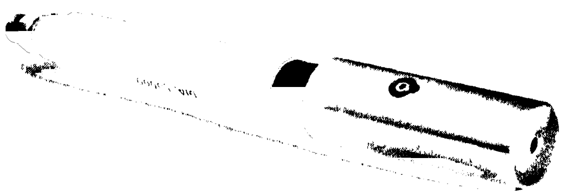
on the free flow of the air and builds up a steady base pressure which, depending on the make of air gage, may or may not show on the indicating device.

The air then travels along through tubes, if the measuring plug is attached to the main frame of the air gage, or through plastic hose to the measuring plug, if the latter is to be more or less portable.

Measuring plugs for air gages are made of hardened steel. Frequently they are chrome plated; in many cases they are equipped with carbide wear liners. In general, they closely

resemble conventional inside diameter plug gages. Before the plug is hardened, however, the air passages are drilled in it and the hardened "calipering jets" are inserted. A photo of an air plug appears in Fig. 2. Its inner workings are shown in Fig. 3.

If an air plug is not directly fastened to the air gage body, it is usually equipped with a handle, as shown in Fig. 3, and a pipe nipple for connecting it to an air hose. The plug itself is also known as the skirt. The calipering or measuring jets, usually separate hardened steel tips, are recessed into the plug or skirt. The jets are connected to the gage's air supply by holes or tubes drilled in the solid plug or skirt as shown in Fig. 3.



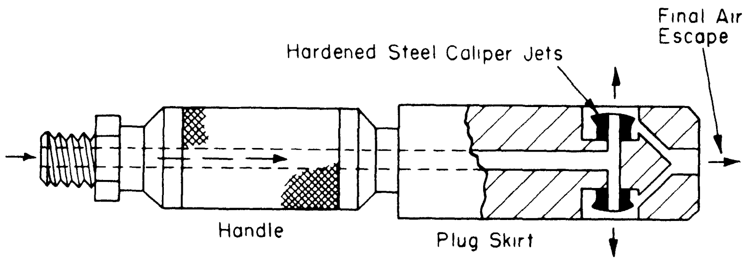


Fig. 2. (Top) One type of measuring plug used with air gages. Fig. 3. (Bottom) Details of the measuring plug shown in Fig. 2.

The plug or skirt is essentially a guide, as well as a holder, for the calipering jets. Its main purpose is to put the calipering jets into position for measuring. The plug is usually anywhere from .0005 inch to .003 inch under the size of the holes to be measured.

If the bore sizes to be measured, for example, are, per blue print, .785″±.001″, the air plug would be made probably at

about .783 inch or .7835 inch, a half-thousandth to a thousandth of an inch smaller in diameter than the smallest size hole it would be expected to measure. Where the workpiece bore happens to come smaller than .783 inch, say, the air plug will not enter the hole and it acts then in the manner of a conventional "Go" plug by rejecting, mechanically, an undersize bore. The air gage plug and calipering jets make an air gage a single-purpose measuring instrument. Of course, various diameters and sizes of plugs can be interchanged with the gage body and indicator but the plugs themselves are single-purpose.

The range of an air gage plug is .003 inch total. Where the holes to be measured come .003 inch larger than the plug skirt diameter the air gage indicator will not register the true workpiece diameter correctly, if at all.

The principle on which the air gage operation is based, is that back pressure will be created when air in motion is deflected from its normal direction of flow. Referring to Fig. 4 the flow of regulated, filtered, compressed air is restricted at the master jet *m* and the indicating device shows what is known as "static pressure." The air continues on through the tubes and the plug passages and issues freely from the pair of calipering jets. The friction and further restriction imposed on the flow of air by the hose, tubes and the small diameters of the calipering jet holes of course builds up the static or base pressure of the system a little more.

How the Air Gage Functions

Now the plug is introduced into the workpiece hole, *w*, Fig. 4. The air, hissing freely away from the jets is deflected. Most of it bounces off the walls of the workpiece and escapes through the final escape outlet, *t*. A little of it may leak away, after it leaves the jets, along the workpiece and plug walls as the direction arrows indicate.

Since the direction of air flow has been changed, back pressure immediately builds up and increases the pressure at *m*, in front of the master jet, causing the indicator to register greater pressure because the escape of air at the jets has been deflected and restricted at the calipering jet orifices.

The smaller the inside diameter of the workpiece, the closer its walls come to the jets, the more abrupt the deflection of the air (there is an effect of a harder bounce off the workpiece

wall) and the greater the general restriction of its escape. Consequently the back pressure is greater and the indicator registers the decrease in diameter literally by a higher pressure reading. If the inside diameter of the workpiece is greater, the whole effect is reversed, and if the inside diameter of the workpiece exceeds the outside diameter of the plug by too much, the back pressure created is too small to register on the indicator.

The sketch of Fig. 4 shows three methods of registering air pressure. There is the U-tube or manometer type, *u*, where

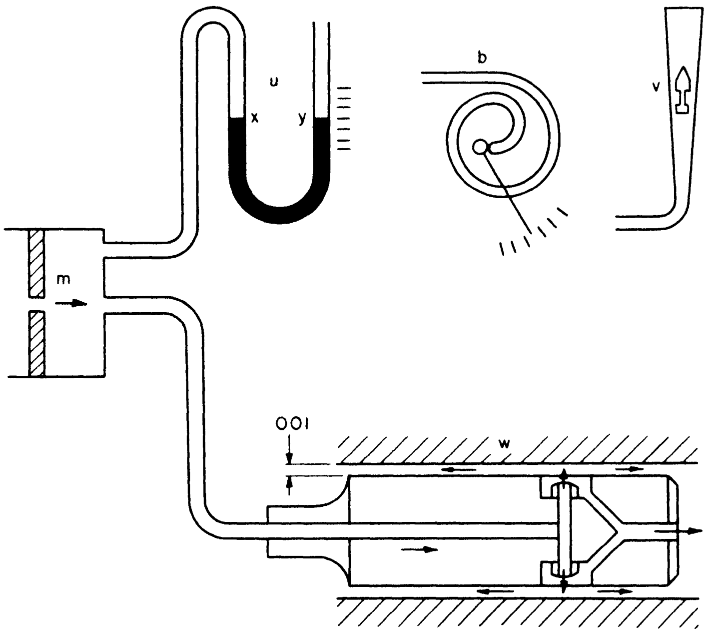


Fig. 4. Schematic diagram showing manometer tube (*u*), Bourdon tube (*b*), and Venturi (*v*) types of air gages and the path followed by the air flowing in an air gage set-up.

pressure unbalances a mercury or water column, the difference in height between x and y registering pressure. The manometer is the most sensitive of the several methods in registering air pressure changes and, on the whole, gives the most accurate reading. However, mercury is scarce and expensive and the water column requires air pressure reductions to about two pounds. Both are inclined to be unwieldy as shop equipment. Hence, manometer gages are usually found only in gage laboratories.

Diagram *b*, Fig. 4 illustrates the so-called Bourdon tube design (characteristic of steam pressure gages for instance) where the air pressure tends to uncoil the spiral coiled tube. This movement is amplified, as in the mechanical indicator, with gears and a pointer or hand.

Sketch *v* shows the Venturi tube method where the air escapes through a tapered tube. Inside the tube is a light weight bobbin, somewhat like a small cork, which floats in the stream of air. The greater the back pressure, the greater the velocity of air flowing through the tapered tube. It carries the bobbin or float up with it to a point where the increasing taper of the tube offsets the "corking" effect of the bobbin.

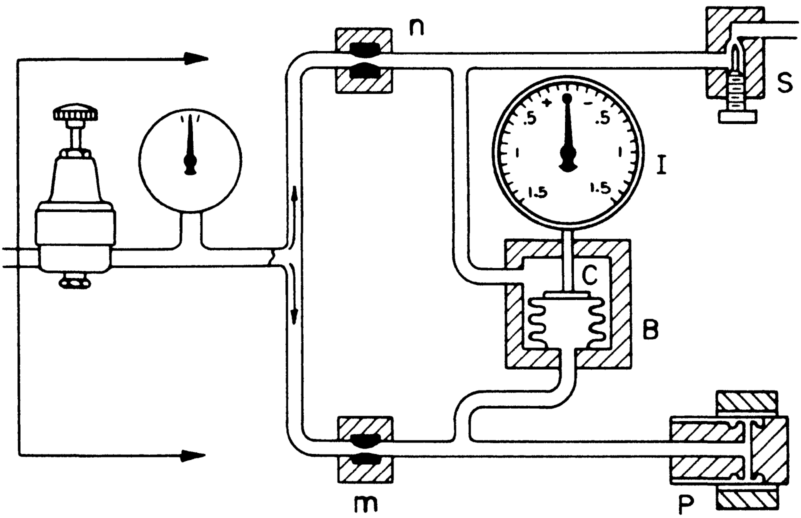


Fig. 5. Elements of a balanced-circuit type of air gage showing direction of air flow.

A later development brought out the balanced circuit type of air gage. In this equipment the pressure indicating mechanism is cut in *across* the two air paths and a built-in gage zeroing valve is provided. Such a "balanced circuit" is shown schematically in Fig. 5.

This design uses, in effect, two master jets, *m* and *n*, one in each branch or circuit, to effect the basic restriction in the flow of air. From the master orifice *m* the air flows to the air plug, as Fig. 5 indicates where it meets the further restriction of the workpiece or the master setting ring. This latter restriction

builds up back pressure inside the bellows device, *B*, causing the bellows to expand or elongate and move the indicator, *I*, above.

At the same time the other half of the air is flowing through the other master jet, *n*, to the setting screw, *S*, Fig. 5. By closing or opening the valve, *S*, the pressure in the sealed chamber, *C*, surrounding the bellows, *B*, can be altered. When the back pressure in *C* is regulated to match the back pressure from the measuring plug, inside the bellows *B*, the bellows does not expand and the indicator registers 0. An advantage of this system becomes apparent after studying the "linear scale" principle described below.

Linear Scale Principle

The air gage takes advantage of the fact that minute differences (down to .000005 inch) in the internal diameters of workpieces will affect the back pressure sufficiently so that the pressure change can be amplified on the indicating mechanism — a difference in .0001 inch in workpiece I.D. showing up as about ¼ inch movement on the indicator dial or column. Such an observation will be accurate, however, only when it is a linear scale reading.

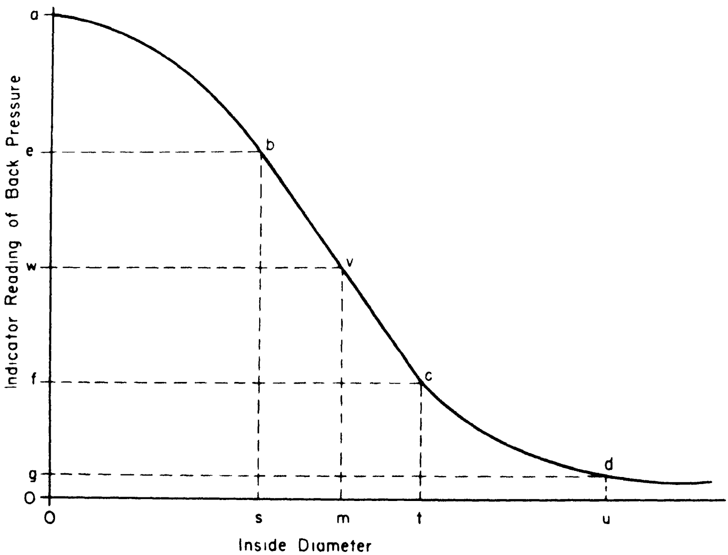


Fig. 6. Air gage pressure-diameter curve illustrating linear and nonlinear scale readings.

The linear scale thesis is best explained, perhaps, by means of a curve like that in Fig. 6. If with an air gage you seal off the air plug caliper jets (see Fig. 3), say with finger and thumb, so that no air escapes, the gage indicator will register maximum back pressure. Such a condition is shown at *a* on the curve in Fig. 6, where the inside diameter is 0 and the indicator reading at maximum.

Suppose then you release finger and thumb a trifle and let a little air escape (an amount that might be equivalent, for instance, to the minimum internal diameter of a workpiece), the indicator would register a little less pressure — an amount such as shown at *e* in Fig. 6, which would be equivalent to an inside diameter like *s* for example. A greater inside diameter, as at *t*, would register still lower on the indicator as at *f*.

If you kept on using a series of workpieces of increasingly larger inside diameters until finally you caused practically no deflection of the air escaping from the calipering jets with an inside diameter as at *u*, you would get a condition of practically no indicator reading as at position *g* on the curve in Fig. 6.

The correct interpretation of the curve in Fig. 6 shows that any indicator readings between *a* and *e*, or between *f* and *g*, do not register the *proportionate* or correct inside diameters (because the graduations on an indicator or a column are equally spaced) but that the indicator readings between *e* and *f* are directly proportional* to the changes in inside diameter between *b* and *c* (or *s* and *t*). The section of the curve between *b* and *c* is known as the "straight line" section in air gage parlance, and the trick is to design and match air gage elements so that any measurements taken by the air gage will be within the dimensional range of *s* to *t*.

With most air gages and under the majority of practical conditions, the dimensional range of *s* to *t* is usually about .003/ inch. In other words, an air gage will register with high precision the dimensions within this range but its readings are subject to error outside of it. An air plug made and marked to check 1.433- to 1.436-inch holes, for example, would be inaccurate for 1.437- to 1.440-inch holes.

*Strictly speaking, there is a slight variation from direct proportionality since the "straight line" portion is really a slight curve, but the effect of such variation is negligible as compared to the value of one scale division.

Basically an air gage is a comparator; it cannot be used as a direct-reading instrument except within the .003 inch range suggested above. With each air gage plug comes either one master ring or a pair of them, depending on the make and type of air gage. Such master ring gages are usually made to tolerances of .00001 inch. If the air gage requires only the single setting master, it is usually made to the mean dimension, halfway between the upper and lower tolerance limits. Where the pair of rings is prescribed, the dial or column markers are usually set to upper and lower tolerance limits. The air gage circuit is adjusted, in other words, so that it will register internal diameters between *b* and *c* on the curve of Fig. 6. All air gages are provided with pressure regulating or setting knobs. The operation of "zeroing" one type of air gage, using a single ring is pictured in Fig. 7. Also shown is another type of gage being checked for the lower limit with one of two ring gages, the other being used for the upper limit.

Courtesy of Federal Products Corp

Courtesy of Sheffield

Fig. 7. Two types of air comparators. (Left) A single ring gage is being used to check the zero reading. (Right) Here, the lower limit reading is being checked with one ring gage; the other will be used for the upper limit.

Effect of Crusted Dirt, Grease, Coolant and Surface Roughness

On the whole it is safer to clean workpiece surfaces that are to be air gaged. While the air from the jets will probably blow off most of the oil, dirt or coolant, it may not happen to

do a thorough job. If the cutting oil is heavy, if the workpieces have been greased or rust-vetoed or if they have become encrusted with dirt, the air may not clean it all off and the internal diameter measured will then include twice the thickness of a foreign film which may be .0001 inch to .0003 inch thick. Some care must also be used, if the workpieces are not cleansed, to make sure that air jets do not splatter oil or coolant onto the clothes or into the eyes.

The matter of surface finish is important in air gaging. The air gage really measures what might be called the pitch line of surface roughness. See the exaggeration in Fig. 8. The air gage measurement indicated would be m and not m_2 which might be called the root depth or major diameter of the hole.

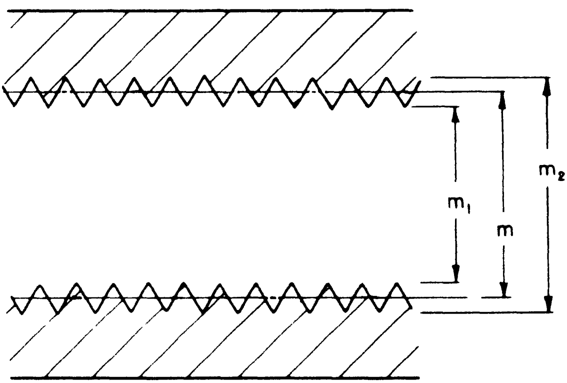


Fig. 8. An air-gage measurement indicates the mean diameter m when the surface is rough.

Nor would the air gage measure m_1 or what might be called the minor diameter of the hole.*

Confusion sometimes arises where the air gage registers dimension m, while a conventional plug gage, or a mechanical indicating bore gage of the types shown in Figures 53 and 54, Chapter 8 will show the hole size to be m_1. (If the tool marks are quite coarse and if the mechanical indicating gage reference and sensitive points have small radii it is possible for the mechanical gage to indicate diameter m_2.)

* The terms used here — pitch diameter, major and minor diameter — are borrowed from the common industrial terminology for the elements of screw threads.

The rule of thumb commonly applied is that air gages will show a troublesome error where the surface roughness of the bore equals or exceeds 100 microinches and for this reason air gaging should then be discarded in favor of mechanical type gages. However, since the range of the air gage does not exceed .003 inch (the equivalent of tolerance limits of $\pm$ .0015 inch), the surface roughness of the bores to be measured by this type of gage preferably should not exceed 60 microinches.

This surface roughness limitation can be overcome by using masters with a surface roughness that is about the same as that of the hole to be measured. Remember the air gage is strictly a comparator and that it is usually mastered with rings. Ring gages are customarily lapped to surface finishes of about 5 microinches. Thus an error would result if the air gage were zeroed against a 5-microinch surface and then used to compare the diameter of a bore with a 200-microinch surface roughness. A good rule of thumb is to be sure the surface conditions of masters and workpieces are within 50 microinches of each other.

Proper Use of the Air Gage Plug

Examination of an air gage plug (see Fig. 3) will show that the hardened spherical jet tips are recessed inside the main plug diameter, usually about .001 inch. The plug proper, or skirt, is really only a guide sleeve which also prevents the jet tips from being worn away from constant application to workpieces. The plug should be repaired, replated or replaced when its outside diameter has worn down to the jet tip diameter.

The plug acts as a centralizer or guide. Ordinarily, it can be introduced into a workpiece with a perfectly natural plugging motion. However, where precisions of .0001 inch or greater are desired, one or two precautions must be observed. The air gage plug must not be used in bores whose internal diameters are .003 inch greater than the plug outside diameter. If the air jet tips are in a vertical line as in sketches A and B of Fig. 9 at the time the gage is mastered, the jets should be kept in the same position when measuring the workpiece. If the jets are horizontal for mastering — as at C, Fig. 9 — they should be horizontal for measuring. Don't mix the conditions.

While the theoretically ideal measuring position of the plug is shown at A, Fig. 9, with equal clearance between each jet

and the bore wall and with the jets perpendicular to the axis of the bore, practically no appreciable error occurs when the clearances are a little unequal. Sketches D, E, F and G show various positions in which the unequal spacings are extreme. These may lead to some errors since the air is deflected more sharply at, say, y in sketch D and less back pressure is built up at the opposite jet at x. But remember the two jets are connected to a common tube. The air gage registers a back pressure that is a mixture, a balance, of the individual pressures set up at x and y, which tends to reduce the indicated error.

Following the same general reasoning, the air gage plug can be tilted a little, as suggested in sketch H of Fig. 9, without

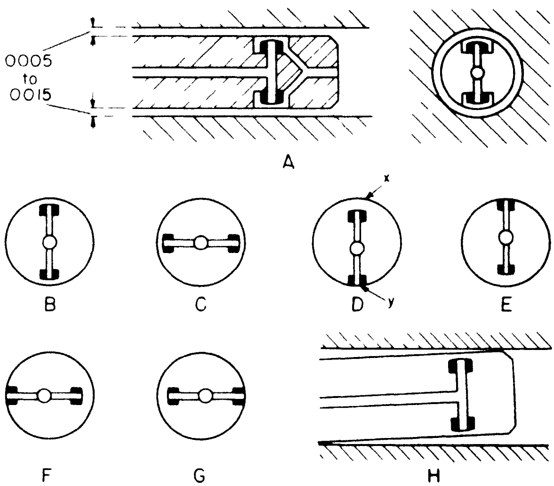


Fig. 9. Air-jet tips should be kept in the same position in measuring the work-piece as when the gage is being mastered. (A and B) Optimum vertical position for mastering and measuring; (C) Optimum horizontal position; (D, E, F, and G) Various extreme positions in which unequal spacings of the jets from the surface being measured may lead to errors; (H) A tilted measuring element usually will not produce a noticeable error.

noticeable error. All the slight variations in position are acceptable provided, in general, the plug outside diameter is within .003 inch of the bore internal diameter.

As ordinarily set up and used, air gaging is the speediest method for checking internal diameters since the operator simply inserts the plug and reads the indicator from piece to piece about as fast as he can move.

Application of Air Gages

Ovality can be explored for by turning the air gage plug; barrel and hour-glass shape, bell mouth, and taper can be explored for by moving the air gage plug back and forth. The manipulation is simpler than with mechanical indicator equipment because the elements of rocking and centralizing can be ignored. Air gages can be used on yielding materials and on fine finish bores, where the mechanical indicating gage and even the conventional plug gage fails, because the air gage exerts but nominal pressure against the walls of the bore.

The type of gaging plug previously described has certain limitations. It cannot be used for gaging porous materials, and any side holes, oil grooves, recesses, or keyways in bores must be watched. Special consideration must be given to projections into the bore. Some of these conditions are illustrated

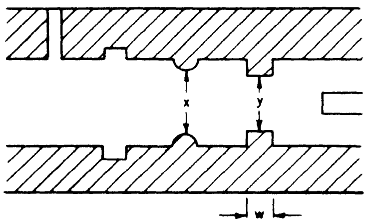


Fig. 10. Diameter x is difficult to determine by air gaging. Correct air gaging at diameter y ordinarily requires that land w be at least 0.100 inch.

in Fig. 10. A diameter like x, for instance, will not be accurately determined with this type of gaging plug. As a minimum width or "land" for which this type of gaging plug is adaptable for accurate measurement, dimension w, Fig. 10, must exceed .100 inch ordinarily, if diameter y is to be accurately gaged.

To overcome some of the difficulties above mentioned, a gaging element is used in which a mechanical component is interposed between the gaging nozzle and the workpiece to provide direct contact with the geometrical feature to be inspected. This mechanical component may be a ball, lever, plunger or blade. To escape, the air from the gaging nozzle must pass between this component and the work surface or, if the material is porous, through the workpiece, itself. The closeness of contact between this component and the work surface governs the back pressure on the air gage, which pro-

vides the reading. This type of gaging element can be used to measure porous metals, and for narrow lands or the mouths of holes.

Maintaining Air Gage Accuracy

In the manufacture and calibration of an air gage and plug great care is used in controlling the three diameters, *a*, *b*, and *c*, diagrammed in Fig. 11. Unless certain ratios are maintained, the gage will be inaccurate. If the master jet orifice (diameter *a*, Fig. 11) becomes fouled with moisture, oil or dirt, the gage will not function accurately. Naturally, the measuring jets (diameters *b* and *b*) must be kept clear. Diameter *c* must not

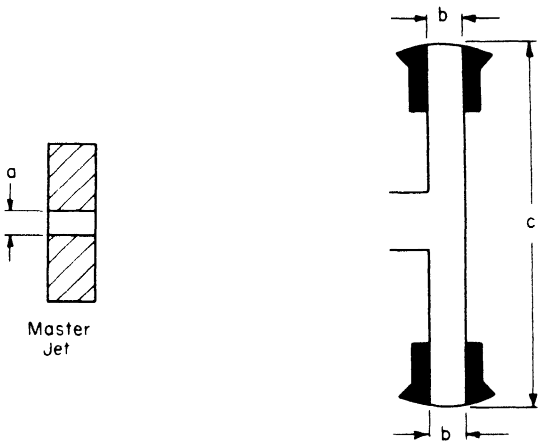
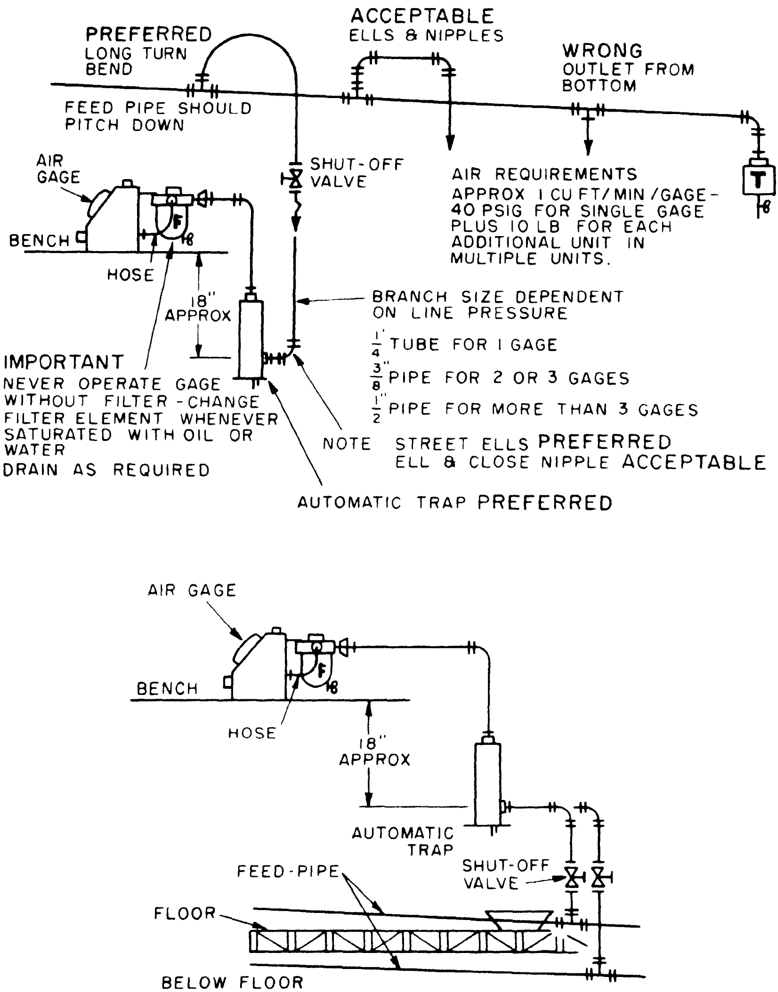


Fig. 11. Three diameters, *a*, *b* and *c*, which must be closely controlled in the manufacture of air gages. In use, diameters *a* and *b* must be kept clean.

be allowed to wear down. Hence, the general requirement that the air supply be clean and moisture free and that dirt, oil, grease or coolant on workpieces shall not be so excessive as to clog the measuring jets.

Should there be reason to suspect air gage inaccuracy, first check for air leaks in all fittings, tubes and connections. Leakage can usually be adequately indicated by corking the measuring jets with the finger tips and watching the indicator. If there is line leakage, the indicator will not remain motionless after the jets are sealed off. Repetition is another test. Try the gage several times in its master to be sure you get repeat readings.



Courtesy of Federal Products Corp.

Fig. 12. Some suggestions for correct installation of air supply piping. (Above) Layout with air line on ceiling. (Below) Layout where branch comes from floor level or ceiling below.

If not, suspect, among other things, fouling of the master orifice or the measuring jets. If you are sure they are clean and you still fail to get repetition, suspect irregular air pressure from the supply line. If the workpiece is dirty, clean it and test again for repetition. Check for unusual surface roughness, rifling, pits or holes in the workpiece.

One of the major causes of air gage difficulty is the quality of compressed air supplied it. Commercial air gages come with filters adequate for ordinary air line dirt, water and oil conditions but not for the dollops and slugs of water and oil often also supplied in some shop air lines along with the air. Commercial air gages also come with pressure regulators satisfactory for most conditions but they are not always adequate for the sharp drops and peaks in pressure present in some unregulated shop lines. Such extreme conditions must be overcome of course before any sort of satisfactory service can be expected of any air gage.

Much harder to detect, however, is an air supply condition which forces an air-oil-water mixture or *mist* into the air gage passages. Sometimes this mist condition will cause more trouble by fouling master jets and plug jets, with resulting inaccuracies in readings and repetition, than an internal stream of clear, condensed water in an air line.

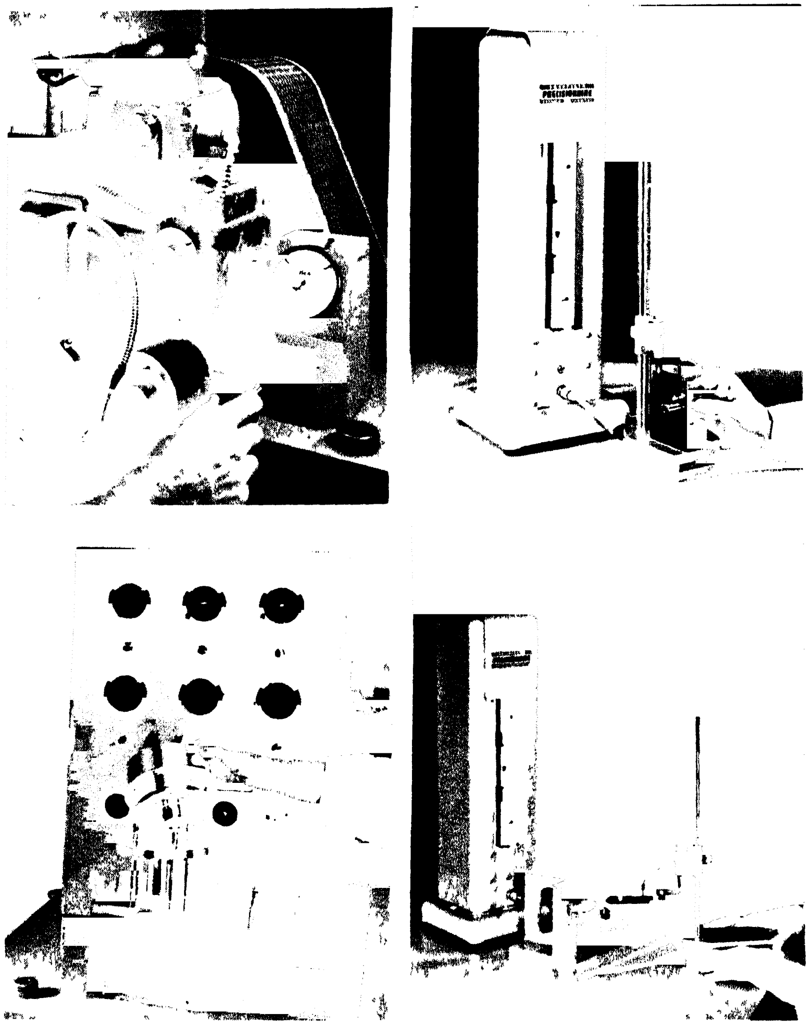
The cure for all of the trouble implied above is adequate and proper trapping of air lines that feed air gage setups. Suitable air cleansing and trapping equipment is available on the market and a shop's maintenance crew has little excuse for supplying badly contaminated compressed air to air gage service.

As temporary expedients, to secure accurate results from air gages over short periods in spite of air supply lines loaded with moisture or oil, the air gage's filter can be drained off every quarter hour or so. Another trick is to open a petcock or valve in the air line which will allow the line to bleed a little steadily.

The diagrams in Fig. 12 are offered to illustrate the importance of clean air and to give a few more suggestions for the installation and maintenance of air gage supply lines.

Air Gaging Applications

Within the scope of a book like this it is not feasible to try to describe the manifold uses of air gaging in industry. Indeed, little more than a hint can be offered. Gage manufacturers advertise air gaging equipment widely and will supply catalogs and descriptive pamphlets. An inspector, to keep adequately abreast of his job, should arrange for access to such literature on modern air gaging and keep informed on this important phase of today's technology.



Courtesy of Federal Products Corp. *Courtesy of Sheffield*

Fig. 13. (Upper left) Using an air gage to check a lapped hole surface. (Upper right) Using an air comparator and height gage stand to check the external diameter of a cylindrical part. (Lower left) Simultaneous inspection of hole diameters and center distances with an air gage. (Lower right) Using an air comparator and height gage stand to check surface flatness.

As has been suggested, the air gage is one of the faster and more precise methods of measuring hole sizes and checking hole conditions. The photographs making up Fig. 13 will give an idea of single and multiple uses of such air gaging equipment.

As mentioned previously, air gaging equipment is also used for checking taper, ovality, triangular out-of-round, flatness, parallelism, squareness, hole location, as well as outside diameter, width and thickness. The sketches in Fig. 14 visualize three of such relationship checks. Air gage equipment can be also made up, for example, to check the outside diameter (of a shaft) and the inside diameter of a bearing and, with a third meter, show exactly the clearance (or interference) between

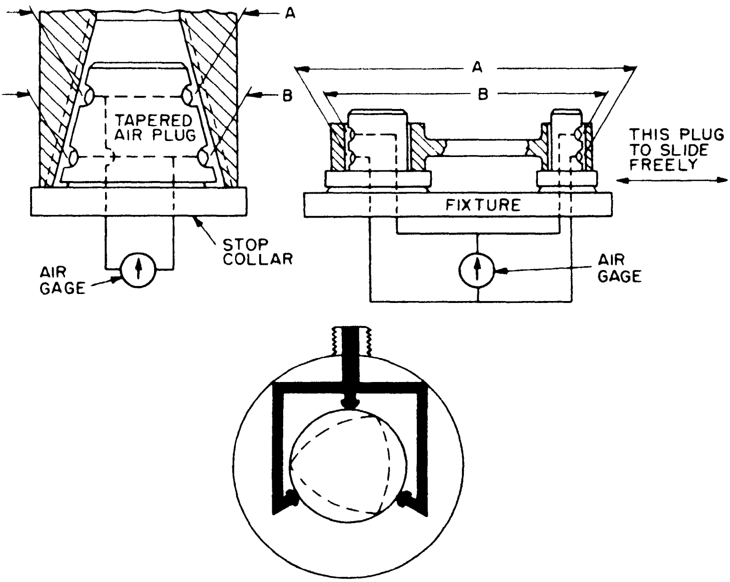
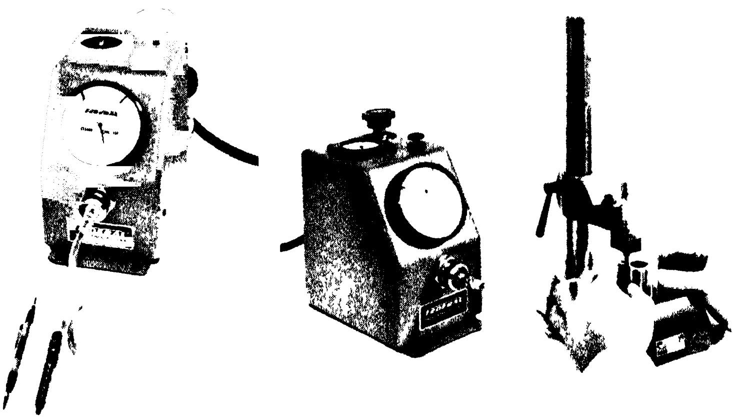


Fig. 14. (Upper left) Using special type of air plug to check accuracy of the taper of a hole. (Upper right) Using air gage and two air plugs to check parallelism between two straight holes. (Below) Construction of an air gage ring for outside diameter measurement. This type of gage is useful for checking taper, ovality, and triangular effect, in addition to checking the outside diameter.

the two. Equipment of this nature is used for the rapid and accurate selection of mating parts in a selective assembly operation.

There are several reasons why air gaging equipment is popular, useful and, in fact, profitable to use. In the first place it is accurate. It will easily and accurately determine a size difference of ten millionths of an inch (.00001 inch). In the second place it is easy to use. It is direct and easy reading as compared, for instance, to reading a vernier or even a micrometer scale.

Trained experts are not necessary. No special manipulation is necessary, again as in the case of vernier calipers or inside mikes. Gaging pressure does not enter the picture as it does where conventional fixed plug gages are used. All these advantages also add up to time and labor saving. Where it takes an accomplished inspector 43 seconds to measure the inside diameter of a bore with vernier calipers (and then not come closer than .001 inch to the true size), an inexperienced operator can check the same hole with an air plug and gage in 4 seconds and be accurate to .00001 inch.



Courtesy of Federal Products Corp

Fig. 15. (Left) Direct-contact type of air gage pick-up cartridge with moving spindle. (Right) This type of gaging element can be used in a height gage stand as shown.

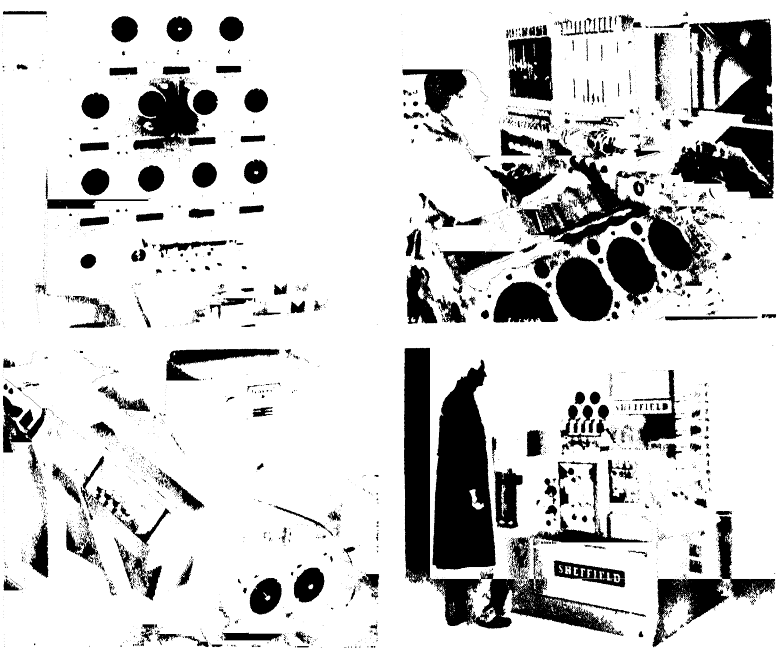
Another development has added to the extent and flexibility of air gage use. This is a specially made attachment which looks and acts (from the outside) like an indicator stem and spindle. It is in effect an air valve.* Figure 15 pictures one of the fountain-pen-size attachments and shows one of them in use in a simple comparator setup. One of the great advantages of the Airprobe type of attachment is that it can be so readily used in a multiple gage setup like that also illustrated in Fig. 14. These "valves" act externally like an indicator stem and spindle. Internally the spindle motion tends to open and close an air jet, restricting the air flow, in about the same way a

* Common trade names are Airprobe, Federal Products Corporation, and Plunjet, Sheffield Corporation.

ring restricts the air flow at the calipering jets of the regular air plug, and thus transferring the measuring motion of the spindle to the air gage indicator or column.

Designs have also been developed whereby the movement of the air gage indicator or meter also simultaneously actuates electric microswitch, resistance, or reactance mechanisms. Thus the measurement or reading can be transferred to electric impulses which in turn, can direct machine control or automatic sorting functions. Figure 16 displays several of these various applications.

In his part of setting, mastering, checking and maintaining multiple and air-electric and special design air gaging equipment, the inspector treats each individual unit as he would a



Courtesy of Federal Products Corp *Courtesy of Sheffield*

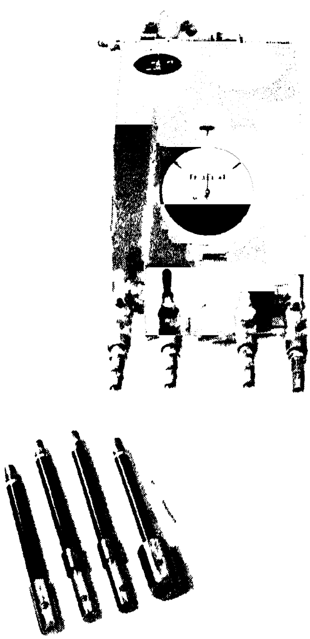
Fig. 16. (Upper left) Use of air gaging units of the type shown in Fig. 15 with multiple indicator panel for checking various dimensions on a shaft. (Upper right) Eight cylinder bores in an engine block are being automatically checked simultaneously at four places for diameter and taper with this air gage equipment. (Lower left) Machine control and automatic sorting units with air-electric indicators used in post-process machine control. (Lower right) Air-electric gage control unit designed to combine, in a single unit, multiple automatic gaging and feed-back control of a series of machines.

single gage, applying the same fundamentals of correct measuring. In each case he should be guided by careful reading of the gage equipment manufacturer's instructions. Usually too, he will be provided with separate manual gaging equipment, of equal discrimination and accuracy, so that he can verify any gaging equipment accuracy and calibration by checking sample workpieces.

Flexibility of Air Gage Systems

Many plants have discovered that once air gaging systems — compressed air supply, traps, filters, valves, and piping, plus air gage meters or columns — have been installed, they can be used for a wider variety of fast, accurate, precise measurement purposes than originally planned for.

As a simple example, consider a machine set-up for drilling and reaming different size holes. An air gage with a valve manifold and a group of air plugs, as suggested in Fig. 17 can

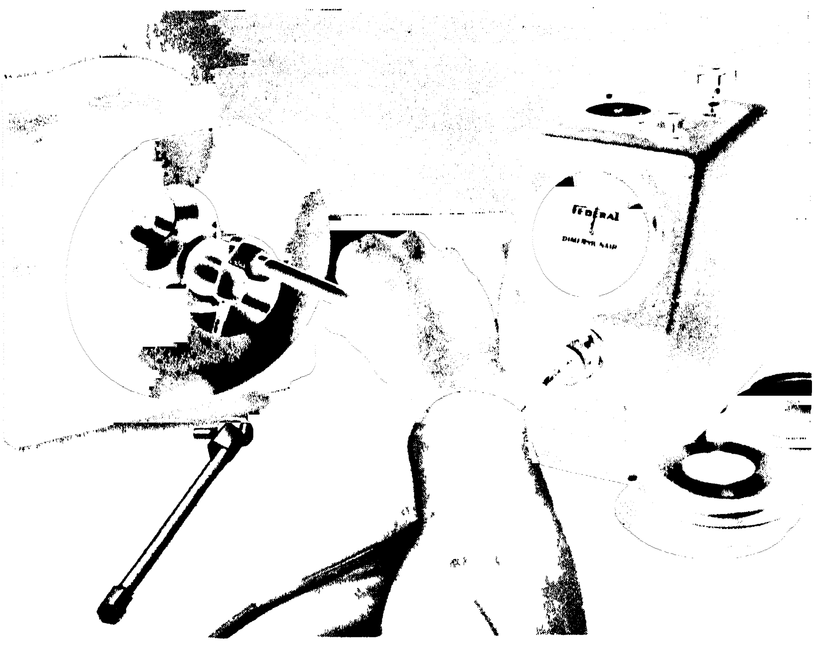


Courtesy of Federal Products Corp.

Fig. 17. By connecting a valve manifold to the air gage outlet, the use of a single air gage can be rapidly adapted to a diversity of plug sizes or other accessories.

be installed at the machine for operator use, or process inspection, as at an inspection batch checking center. One air gage and meter set-up can thus serve to get multiple measurements quickly. The air plugs can be readily changed for different size holes to accommodate diversities of production.

Air gage manufacturers are also supplying adjustable bore gage heads, which attach to an air gage, and by means of which a large variety of hole sizes, from 1/4 inch to 8 inches, can be precision checked. This arrangement is shown in Fig. 2.



Courtesy of Federal Products Corp.

Fig. 2. Hole gage heads, similar in construction to dial bore gage equipment, are available for connection to air gages. These feature adjustment mechanisms permitting their use in an extended range of hole sizes.

The adjustable air bore gage often solves the problem of precision measurement of large diameter holes and is especially adaptable to the small lot sizes of job shop work.

While air gaging is one of the faster and better ways of measuring holes, its use is not confined to inside diameters. It is being brought in increasingly to check outside diameters. Gage manufacturers supply air snap gages of the type pictured

Courtesy of Federal Products Corp

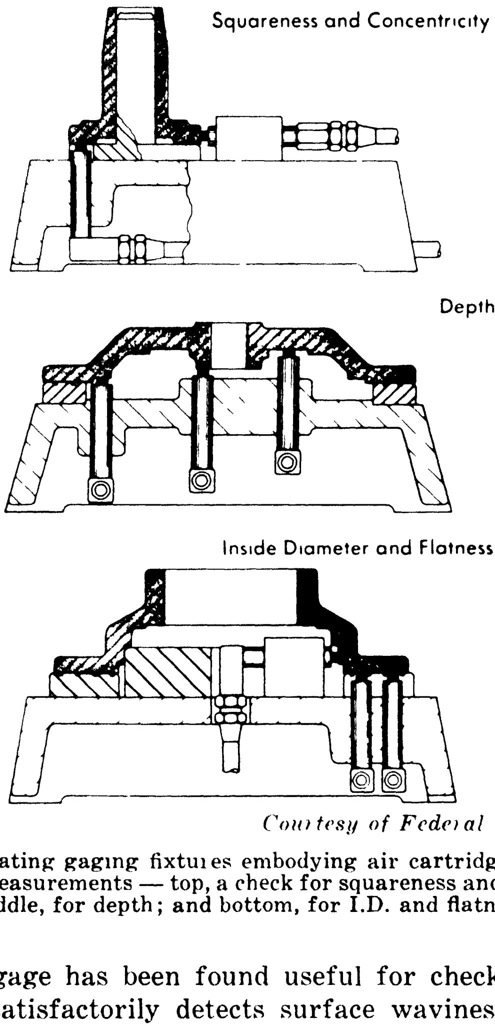
Fig. 3. Featuring an air gage attachment built into an indicating snap gage design.

in Fig. 3 which have the advantage over fixed snap gages and indicating caliper gages of being able to detect size differences readily and accurately in terms of 20 and 10 millionths. Air rings like that pictured in Fig. 4 are used for shaft measurement and, because they offer 3-point air jet contact, are especially useful on centerless ground parts.

Courtesy of Federal Products Corp

Fig. 4. Shaft and cylinder O.D.'s are measured by an air gage through an air ring.

The addition of air cartridge devices to air gages has given the latter almost unlimited measurement facility. There are many situations where the use of the air cartridge is to be preferred over the everyday gear train indicator. In fact, the air cartridge has solved measurement problems that the regular air plug has been unable to crack. Their small size enables the gage designer to place them in spaces where neither indicators or air plugs could be used. Fig. 5 offers three examples of many such quandaries resolved by air cartridges.

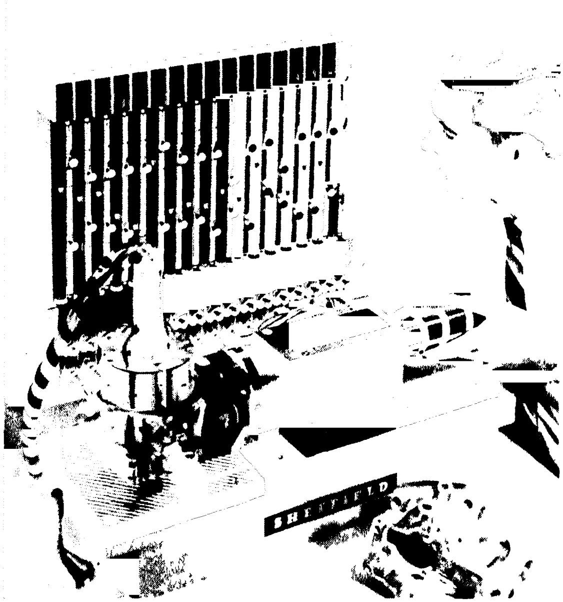


Courtesy of Federal Products Corp

Fig. 5. Illustrating gaging fixtures embodying air cartridges for unusual and difficult measurements — top, a check for squareness and concentricity; middle, for depth; and bottom, for I.D. and flatness.

The air gage has been found useful for checking internal tapers. It satisfactorily detects surface waviness or lack of

flatness, and in addition, out-of-round, eccentricity, hole location, width and thickness. It is also especially adaptable to multiple gaging equipment. Fig. 6 illustrates an air gaging set arranged for the measurement of seventeen different characteristics. The inspector would do well to get acquainted with the variety of modern air gaging applications available, information which air gage manufacturers freely offer in a multiplicity of catalogs, brochures and bulletins.



Courtesy of Sheffield

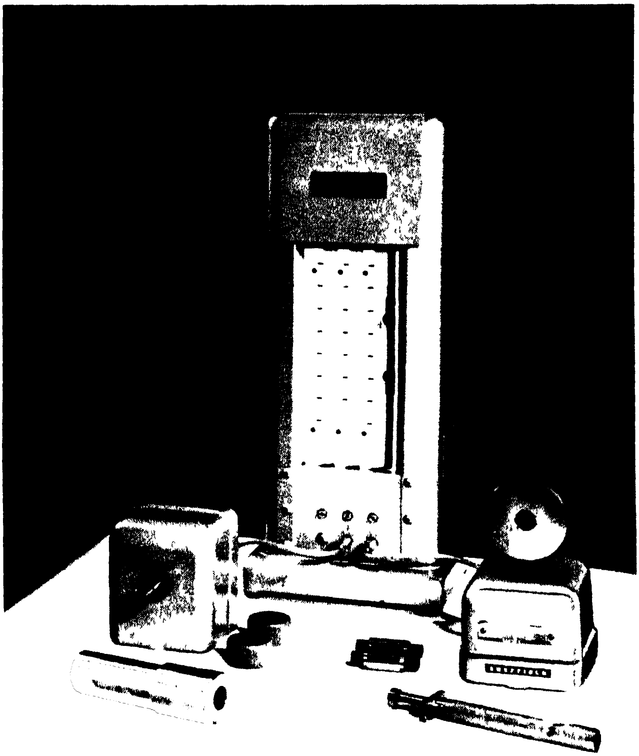
Fig. 22. With this air gage setup, measurements of 17 different characteristics can be taken simultaneously or individually.

Selective Assembly by Size

Air gaging is unique among all systems in its ability to match cylinders and holes — shafts and bearings — to any desired fit, and in this era of close tolerances this property of an air gage circuit is of immense help. To produce shafts in any sort of quantity consistently within a tolerance of .0001-inch or less is difficult, expensive and sometimes practically impossible. Likewise, or even worse, is the job of boring, reaming, grinding and honing a series of holes to close tolerances. The frequent result is fits between shaft and bearing

that are too much on the loose side with assemblies that are noisy, that vibrate or that wear rapidly; or in reverse, fits that bind and heat up.

Air gaging equipment can be made up into a "matching gage" with a manifold connector and a special internal circuit which ties simultaneous I.D. and O.D. measurements together



Courtesy of Sheffield

Fig. 7. Special air gage equipment assembled as a "matching gage" unit.

with the meter. Figure 7 illustrates one such piece of equipment. The diameter of the hole is sensed on one unit — usually a plug — while simultaneously the O.D. of a shaft is being sensed in, usually, an air ring. The two measurements are so interconnected through special internal air circuitry that the

meter registers only the *difference* in the two sizes. Another way of looking at it is to consider the shaft, say, as the master and that the hole size is being compared with it, or vice versa.

One way to use a matching gage is to mark a shaft (or use a master cylinder) and put it in its side of the gage. Then succeeding hole pieces are tried on the other side. Those holes showing clearances within tolerance are marked. On other occasions, shafts are mated against a master ring. A third way is to gage in the manner described above until a pair — shaft and hole — is found that suitably matches. The two are marked and the routine continued for the next pair.

Depending on the magnification and resolution of the air gage, pieces can be matched within a few millionths clearance. Taper, out-of-round, lobing and similar troubles can be detected and their effects as obstacles to a good fit considered. A zero or negative reading on this type of air gage spells interference. It must be remembered that actual diameters of holes or shafts are never registered on mating gages, only the differences in sizes.

High Magnification Air Gaging

Another recent trend has been the introduction and use of air gages for measurements closer than 50 millionths with corresponding meter dial or column scale divisions of .000020 inch, .000010 inch or .000005 inch respectively. However, as measurements with air are undertaken that are finer than the more or less standard resolution of 50 millionths — half a "tenth" — difficulties and inaccuracies emerge. A quick study of one principle of air gaging may supply clues as to why an air gage is not always reliable in that last millionth or two of range which look so authentic on the dial or column.

The round column or shaft of air issuing from the plug orifice or jet and impinging against the workpiece is often the key to the situation. Its true shape is important to ultimate accuracy. If the air stream spreads, "mushrooms," too much, if its shape is distorted, if part of it tends to stream away from the air column, there may be variations in back pressure and consequent fluttering and inaccuracy at the metering device.

Sketch A in Fig. 8 gives an idea of the "air curtain" as it is sometimes called and its cylindrical shape (which is perhaps

the ideal) while sketch B pictures the air going astray. The design of the jet outlet, and the workmanship applied in making it, affect the air curtain favorably or unfavorably. Damaging the mouth of the jet, or letting dirt and oil collect and harden there, lowers effective accuracy. The outer shape and dimensions of the jet are also important; if they are not properly designed in the first place or are not kept clean and unscarred, accuracy sapping air turbulence can occur.

The amount of clearance between the air plug jet and the workpiece surface (see sketch B, Fig. 8) becomes more important and more exacting as the air equipment is required to

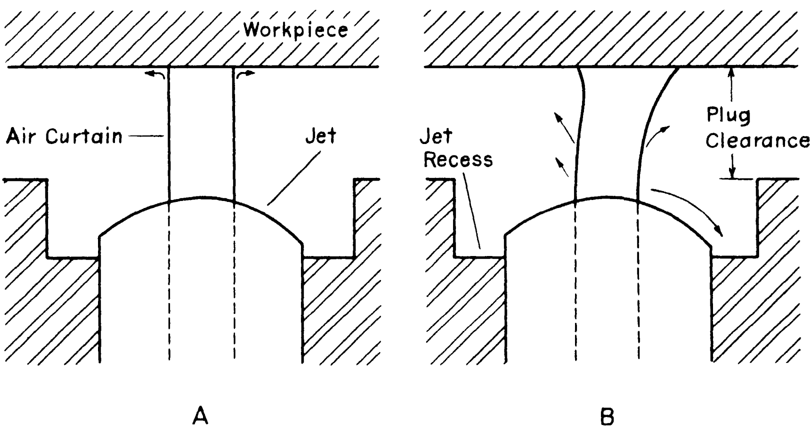


Fig. 8. Diagram of the air curtain and its deformation.

gage size differences in fewer and fewer millionths. The closer the jet outlet comes to the workpiece the shorter the air curtain and presumably the more accurate the back pressure. Such clearances can be as little as .0002-inch, their amounts being determined by the gage manufacturer. Hence, master ring wear now readily affects measurement accuracy and rings need to be checked and replaced more frequently.

Workpiece and master surface conditions have an immediate effect on the millionth measurement accuracy of extra high magnification air gaging. If there is no measurable surface roughness on either master or workpiece, surface finish error can be forgotten. If the surface roughness of master and workpiece are alike or differ by something less than a microinch, the measurement error is considerably reduced if not

nullified. Type, direction and lay of surface condition also has its effect on the impinging air curtain and cause unpredictable discrepancies.

Make a point of checking possible manipulation errors by deliberately wiggling, turning, twisting or canting the master ring or workpiece on the plug of a high magnification air gage, or a shaft inside an air ring, to see whether the position of either the master or workpiece could cause any discrepancies in repetitive readings. If plug or air ring are used steadily, they should be checked regularly for wear. Wear down must not increase the permitted "clearance" shown in Fig. 8 beyond tolerances specified by the gage manufacturer.

The design of each make of air gage with its plugs, air rings and accessories might be called a closed corporation. This is to say that each manufacturer has adopted his own combinations of jet diameters and clearances, of internal master jet I.D.'s and other features of his circuitry. Any size plug made by manufacturer X will work on X's gage, for example, but not on manufacturer Y's gage.

From time to time "replacement" jet plugs for all makes of air gages appear on the market, plugs and air rings that are not made by any air gage manufacturer but as a product of some machine parts company. Usually the advantage mentioned is that of lower price or faster delivery. Probably this type of part had better be carefully calibrated especially before use on a high magnification gage.

The inspector should guard against another source of confusion where a few high magnification air gages may be mixed in among a number of regular air gages on the factory floor. Each air gage manufacturer marks his plugs, air rings, air cartridges and other accessories for the particular magnification of his make of air gage they are to be used with because he knows high magnification plugs or accessories will not work on regular gages and vice versa. A little care and attention may save embarrassment in this respect.

Fork Gaging

Another technique in air gaging, recently developed, has been labeled "fork gaging." Its use is limited to internal grinding. It continuously registers the change in an inside diameter as the grinding proceeds, acting in most respects in a hole, in

the same fashion as the type of machine control caliper gage described in Fig. 9 of Chapter 9 of Inspection and Gaging does on shaft, cylinder and O.D. grinding.

A fork gage is yoke or U shaped, so formed and dimensioned it can occupy the crescent shaped area between the work and

Courtesy of The Heald Machine Co

Fig. 9 Air fork gage in working position on an internal grinder.

the wheel. The view in Fig. 9 and the diagrammatic sketch in Fig. 10 offer a pretty clear idea of how it works. Air is fed from the air gage (which can be mounted anywhere convenient on or near the internal grinder) through air passages in the yoke to a pair of sensing jets, one at each tip of the fork as indicated in Fig. 10. The air fork is usually clamped in some sort of special design hinge device (one of which appears in the photo of Fig. 9) so that the air fork can readily be flipped into gaging position after setup or readily retracted. Such a jig locates the fork on the hole center line, without the fork touching the sides of the hole; thus assuring accurate measurement and no burnishing. The jig also permits longitudinal adjustment of the gage.

A fork gage can be mastered and the air gage zeroed by substituting carefully centered master rings in the internal

grinder in place of a workpiece. It should receive the same careful cleaning and maintenance as any air plug and be checked for O.D. and jet surface wear and damage. It is necessary too to check the two arms of the U or yoke to be sure they are reasonably parallel and not warped, twisted or bent out of line.

Production people sometimes resent air forks because, at best, they do occupy some of the space within the hole and

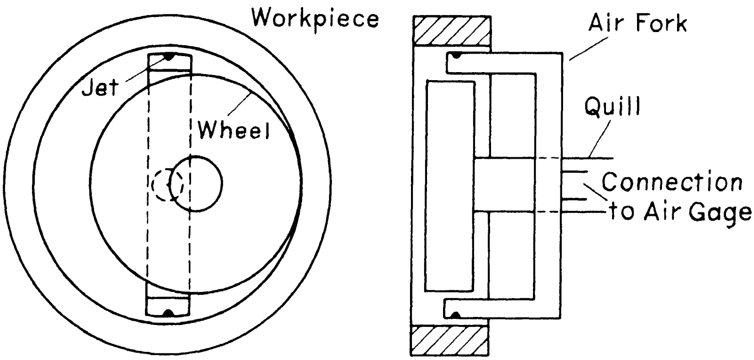


Fig. 10. Diagram of the fork gage principle.

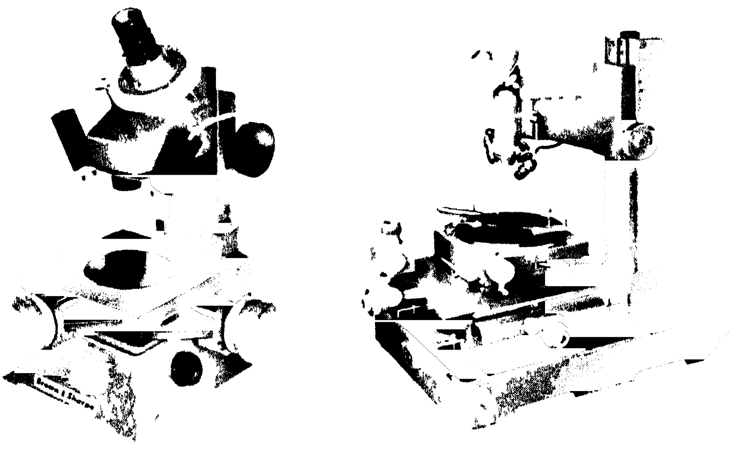
hence they are unable to start internal grinding operations with maximum wheel diameters. For similar reasons there is a minimum I.D. (about 1.25-inch) below which a fork gage cannot be used. Information of this sort can be sought from the air gage or internal grinder manufacturer. Also information can be obtained concerning air plug mechanisms that reciprocate in unison with the grinding wheel to register accurate size control of smaller holes.

The air fork can be used in a "manual" sense in that the grinder operator can continuously read his air gage meter and stop grinding when it shows finished size. More frequently in modern machining, however, the fork gage is connected to an air-electric system whose switch or transducer elements automatically signal the grinder what to do and when.

CHAPTER 11

Optical Measuring and Inspection Equipment

By magnifying a workpiece or a part of it and by using cross hairs, graduations, and scales, methods of measuring have been developed whereby the workpiece is more or less literally only looked at. One such type of apparatus is the toolmakers' or measuring microscope, equipment like that illustrated in Fig. 1.



Courtesy of Brown & Sharpe Mfg Co *Courtesy of George Scherr Co*

Fig. 1. Two commercial types of toolmakers' microscopes.

This instrument consists of a microscope mounted so it can be readily adjusted and focused over the work, and a table or stage with adjustable lighting units to illuminate the work. The table is equipped with clips, clamps, a vise and/or centers

for holding various sizes or shapes of workpieces within the field of the microscope.

To facilitate measurement, cross hairs appear also in the view seen through the microscope. Depending on the equipment furnished or specified, the cross-hair arrangements may appear as in any of the sketches in Fig. 2 — as a pair of intersecting center lines, sketch A, which can also be turned as at B, or as two sets of parallel lines, C, which can be turned as at D.

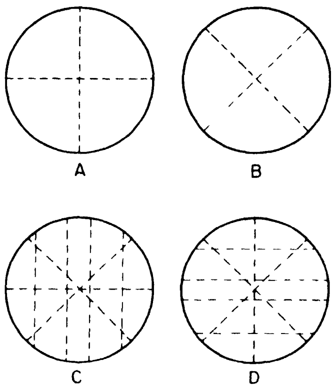


Fig. 2. Two cross-hair arrangements used with toolmakers' microscopes.

The table moves on cross slides and is equipped with micrometer screws for fine adjustment. Usually the micrometer thimbles, see Fig. 1, read directly in .0001 inch-units. The table can be moved laterally or longitudinally across the field of the microscope and is usually equipped with clamps and stop devices so that the exact amount of this movement, beyond the 1-inch range of the micrometer screws, can be controlled and measured by inserting gage-block stacks.

How the Toolmaker's Microscope is Used

The toolmakers' "mike," as it is sometimes called, has its greatest utility in measuring odd profiles, hole locations, and the locations of odd profiles, angles, etc., especially on thin flat stock where conventional methods of measurement are difficult. It is useful, too, in die-sinking problems and for checking jigs. Most measuring microscopes are equipped with a transparent protractor attachment, the view of which can be included in the microscope field for measuring angles. To assist

further in odd measurements, the table or stage can be revolved under the microscope or it can be tilted.

As a simple example, the outline of a reasonably intricate workpiece is offered in Fig. 3 with the relevant, desired dimensions shown by letters. When the piece is clipped on the table of the micrometer and the glass focussed, only a small part of the object or workpiece will be seen through the eyepiece. This magnified area is known as the field of the microscope.

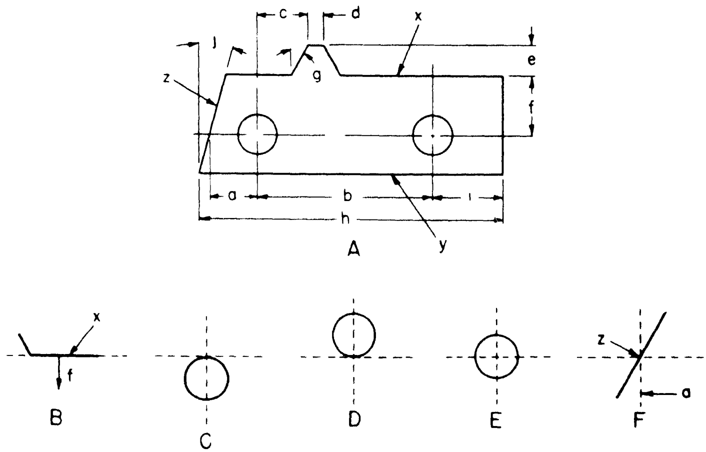


Fig. 3. (A) Work-piece and relevant dimensions which are to be checked using a toolmakers' microscope. (B through F) Steps in obtaining the various dimensions shown in (A).

Perhaps dimension f would be checked first. The workpiece is moved around on the table under the microscope until the edge x appears parallel to the horizontal cross hair. The workpiece is clamped down and the whole table is slid up until workpiece edge y appears under the cross hair, just as a check to see that the workpiece is clamped 4-square to the table.

The whole table would be moved again until edge x is registered squarely under the horizontal cross hair, as shown at B in Fig. 3. The reading of the micrometer spindle regulating the up and down motion of the table is read and recorded at this point. The workpiece is then moved up by turning the up and down micrometer screw and over by turning the right-to-left micrometer screw. The combined motion will bring one of the holes into the microscope field. The hole is centered on the vertical cross hair and its upper edge is located tangent to the

horizontal cross hair as shown in sketch C. The reading from the up and down micrometer screw is then recorded.

Again the workpiece is moved until the horizontal cross hair is tangent to the lower edge of the hole, as at D, and the micrometer reading is recorded. The difference between reading C and reading D is, of course, the diameter of the hole. Half of this figure is now added to reading C and the micrometer thimble is turned to this figure to bring the horizontal cross hair into the center of the hole as at E. The difference between the reading at E and the previous recorded reading showing in sketch B gives dimension *f* of the workpiece.

Now the table is moved along horizontally until intersection *z*, see sketch A in Fig. 3, appears in the field and the cross hairs are centered as shown in sketch F. The right-to-left micrometer reading is then taken. The workpiece is then moved over until the edge of the left-hand hole appears. Applying the technique just described for getting dimension *f*, dimension *a* is found.

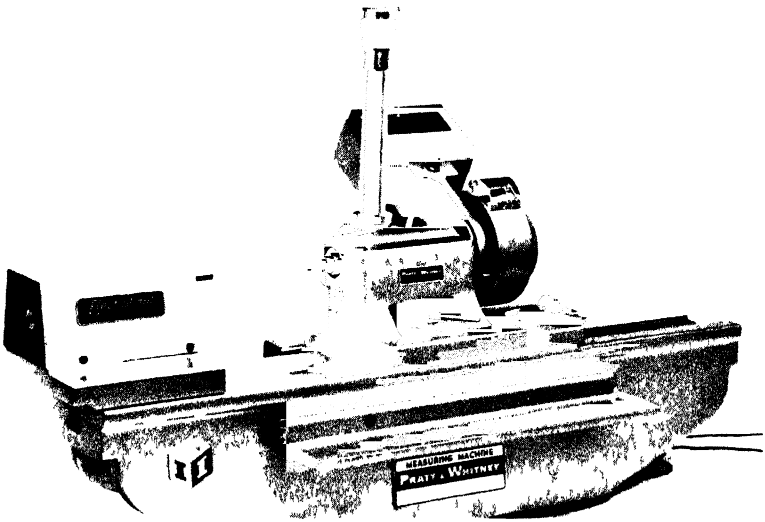
The rather long and detailed instruction just given, in connection with Fig. 3, will be better understood, of course, after the inspector has had a chance to use a toolmakers' microscope. The same geometrical and locating principles apply to securing all the other dimensions of the workpiece shown in Fig. 3. For angles like *g* and *j*, the protractor attachment is brought into use, the protractor hair line being registered on the slanting edges and the angle being read where the hair line intersects the protractor scale.

Adjusting the Microscope Lighting

One or two warnings in connection with the accurate use of a toolmakers' microscope should be issued. The light from the lighting attachments and the general illumination should be so directed and modified that a clear, clean image of any workpiece edge appears in the eyepiece after the microscope is sharply focussed. If the light is too intense, too close, or at the wrong angle, a reflection or "halation effect" appears under which it is difficult to exactly register a hair line on the true edge of the workpiece. If the workpiece is thick, if it has depth, and this is especially true in trying to pick out the true edge of a hole, a degree of fuzziness known as aberration confuses the eye. This is because the eye sees down into the hole. For greatest accuracy change the lighting and the focus until halation and aberration are at a minimum.

The Measuring Machine

Related distantly to the toolmakers' microscope and also to the Supermicrometer is the measuring machine illustrated in Fig. 4. In those shops where one of these instruments is used, always in a temperature-controlled room, it provides a standard of measurement with an accuracy to .00001 inch. Briefly it consists essentially of a master bar, dividing screw (like a micrometer screw), and a means of controlling measuring pressure, all mounted on a rigid bed. The master bar is graduated at each one-inch interval by extremely fine hair lines which are visible only through the mounted microscope. Hair lines in the microscope are matched to the hair lines on the measuring bar. The intervening inch of space is subdivided by the micrometer screw and enlarged thimble which, also read through a glass, enables the .00001-inch discrimination. The tail stock contains the spring loaded (1½-lb.) reference anvil.



Courtesy of Colt Industries Pratt & Whitney Machine Tool Div

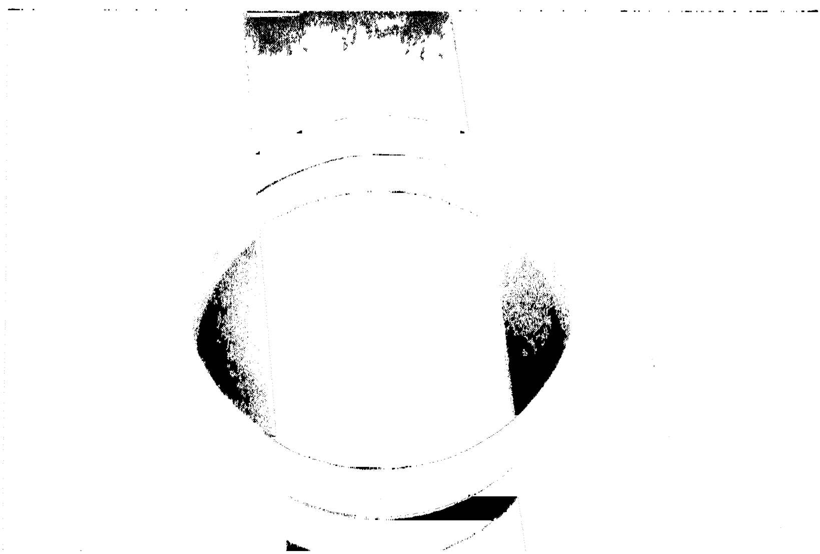
Fig 4 Commercial measuring machine that measures directly to 0 00001 inch

Needless to say, an ultra-precision instrument such as a measuring machine is not made generally available. Usually, one man is assigned to use it and to take care of it. Any and

all of the rules pertaining to instrument care recited thus far apply to this machine. Even the heat transfer from the observer's body may affect its accuracy, to say nothing of a fleck of dust, a miniscule of grease or sweat or the outrage of the minutest scratch or nick. It is checked and calibrated only with master gage blocks.

The Optical Flat

Essentially, an optical flat, as Fig. 5 illustrates, is a highly polished piece of transparent material such as plate glass, optical glass, pyrex or fused quartz, the latter being the best



Courtesy of The Van Keuren Co

Fig. 5. Typical optical flat.

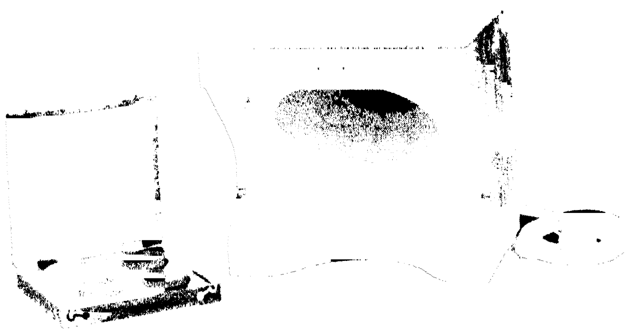
though the most expensive material. Optical flats are cylinders varying anywhere from about 3/8 to 3/4 inch in thickness and from about 2 to 4 inches in diameter. At least one circular surface is polished so perfectly flat that surface waviness, warp or irregularity is virtually immeasurable. Optical flats can be obtained with both circular surfaces guaranteed flat and perfectly parallel to each other. However the single specially flat surface is the more customary, and less expensive; it is differentiated by an arrow pointing to it as shown in Fig. 6. For the best use of optical flats a source of mono-

Courtesy of The Van Keuren Co

Fig. 6. The working surface of an optical flat is indicated by an arrow pointing to it. Some optical flats have two working surfaces flat and parallel to each other, hence are marked with a double arrow as shown at the left.

chromatic light usually is supplied. Such a light source is shown at the right in Fig. 7.

Optical flats provide a simple and rapid means of checking the flatness of surfaces that have been made very accurately. In testing such surfaces, the flat is placed on the work, after removal of all dust or dirt, and a monochromatic light is directed onto the work. If the work surface is now viewed through the optical flat, a series of alternate light and dark bands will appear as in Figs. 5 and 6. The dark bands are called interference bands.



Courtesy of The Van Keuren Co

Fig. 7. (Left) Set of optical flats. (Right) Source of monochromatic light.

How the Optical Flat Works

When a series of straight interference bands is seen, as in Fig. 6, it indicates that there is a very slight wedge of air between the work surface and the bottom surface of the optical flat. The bands take a direction at right angles to the slope or direction of the wedge. The number of bands per inch indicates the steepness of the wedge, which increases in thickness from the point or side of contact at the rate of one-half wave length (0.0000116 inch for commercial monochromatic light sources) per dark band. A pronounced light spot or line indicates the point or line of contact.

The dark interference bands show the points or spaces where the light waves, reflected from the work surface, interfere with the waves reflected from the under side of the optical flat. The light spaces show the points or spaces of reinforcement. It is the dark or interference bands which indicate the highly exact and useful measuring unit of 0.0000116 inch. Straight, parallel and evenly spaced bands, as in Fig. 6, indicate a flat surface, while curved irregular bands, as in Fig. 5, indicate a curved or irregular surface, as will be explained.

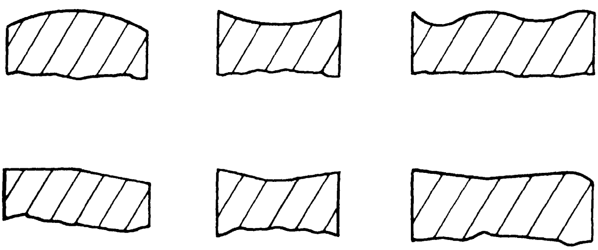


Fig. 8. Some of the surface conditions (exaggerated) which may be detected with the aid of an optical flat.

When the optical flat surface is in perfect contact with a perfectly flat workpiece surface, no interference occurs and no bands appear. However, workpiece surfaces almost inevitably possess irregularities or the contact between the flat and the workpiece is seldom perfect and effects like those exaggerated in Fig. 8 are registered by interference bands.

For successful use of an optical flat the workpiece surface must be smooth, clean and bright enough to reflect light. An optical flat can be used with daylight or ordinary electric light but the interference fringes are vague and ragged if they are

discernible at all. Daylight and most electric light is a mixture of some part or all of the spectrum and each color light has a different wave length. A monochromatic light, or light having predominantly a wavelength of 0.0000232 inch is used in industrial work to secure sharp interference bands.

Correct Way to Use the Optical Flat

Professionally, the optical flat is used in the following manner. First be sure that the flat and the workpiece are clean and free from grit, dust, oil or fingerprints. This is usually accomplished by swabbing them with grain alcohol and polishing the surface of each with clean chamois or paper.

Rest the optical flat carefully on the workpiece. Never wring an optical flat; it scratches too readily and the scratches are an abomination. The flat will ordinarily contact the workpiece at one edge or area but a so-called air wedge will be built up under the rest of the flat. The flat is carefully but firmly, and evenly, pressed down on the workpiece with two fingers until interference bands become discernible. The closer the flat is pressed to the workpiece, the thinner the air wedge or, in other words, the wider apart will be the interference bands.

Lift the flat from the workpiece; never slide it off. If it appears that the contact with the workpiece is not good — if the light bands are not satisfactory — don't slide or wring the flat and workpiece together. No, lift the flat and set it down again, applying vertical finger pressure at several locations on the upper surface of the flat until satisfactory bands appear. In other words, the flat may be rocked and pressed but it never should slide, creep or wring. For best interpretation, the adjustment of the flat should produce interference bands between $\frac{1}{8}$ inch and $\frac{1}{4}$ inch apart and, depending a little on the area of the workpiece, three fringes at least should appear.

Even though the operator follows the above procedure carefully, interference bands may not appear. Such circumstances may be caused by dirt or dust between the work and flat, a burr on the work, by grease, or by lack of sufficient polish on the work to reflect the light.

Whether the bands are far apart or close together, each one counted from the point or line of contact of work surface and optical flat indicates a separation of 0.0000116 inch between

them. The diagram in Fig. 9 illustrates this in exaggerated form. At a distance of 7 bands from the line of contact c-c, the optical flat is separated from the work surface by a distance of 7 × 0.0000116 inch or .0000812 inch. Thus, the thicker the air wedge between flat and work surface, the more fringes closer together or, vice versa, the thinner the air wedge the lesser count of fringes farther apart. Actual measurement is taken by counting the fringes and multiplying that count by .0000116 inch.

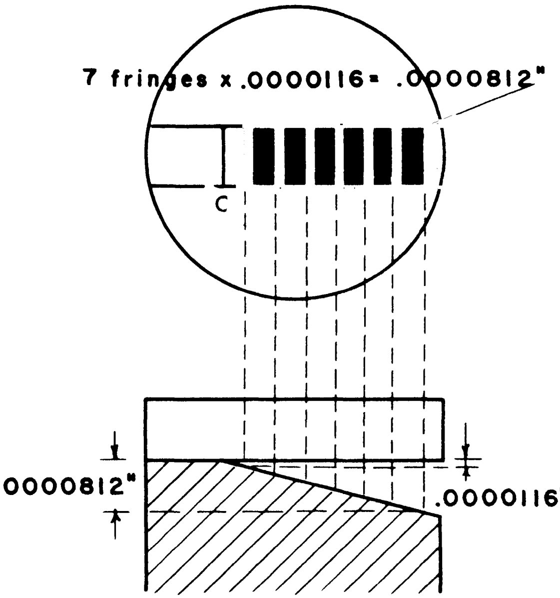


Fig. 9. Diagram showing the geometric relation between the half-wave lengths of the monochromatic light and the thickness of the air wedge under an optical flat.

For practical inspection purposes the optical flat is used mostly to check surface flatness such as the condition of gage anvils, gage blocks, surface plate areas and other precision surfaces. Optical flats are also used to calibrate the thickness of a gage block in comparison with a master block.

Interpreting the Light Band Patterns

Interpretation of the pattern of light bands is, of course, also important. If a surface is concave in the form of a conical crater, the band pattern will look something like Fig. 10-A;

if it is a convex cone, like 10-B. For a circular crater or hump, the bands would be uneven — narrowest and spaced closest together where the sides of the crater or hump were steepest and widest and spaced farthest apart where the slope was the least. To test whether a crater or hump is present, press down in the middle of the flat. The rings will move inward if it is a crater; outward, if a hump. In other words the rings will move towards the thickest part of the air wedge.

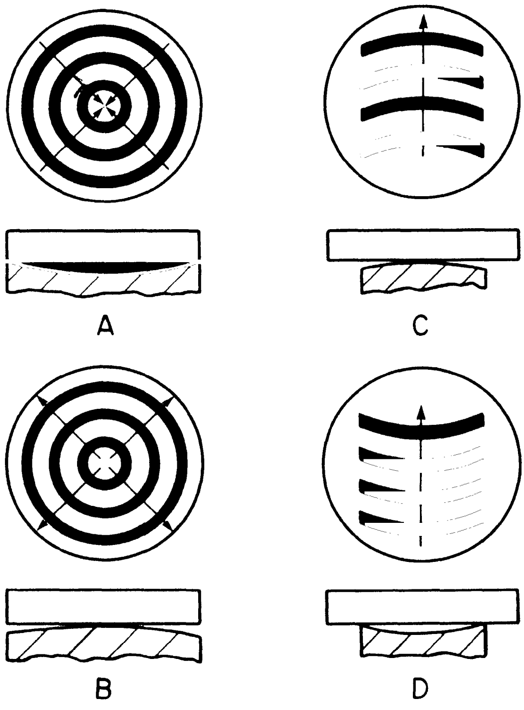


Fig. 10. Various conditions of a work-piece surface and the corresponding interference band patterns when viewed through an optical flat.

The effect of a cylindrical surface on a rectangular work-piece is illustrated in Figs. 10-C and 10-D. To determine whether the surface is cylindrically concave or convex, press down on the middle of the flat. If the rings move as if they were bows shooting an arrow, the surface is convex; if they move in the opposite direction, the surface is concave.

All sorts of effects may be seen through an optical flat. A few of them are interpreted in Fig. 11. Needless to say, if

the interference bands are straight and parallel to each other, the workpiece surface can be considered flat at least within a few millionths of an inch.

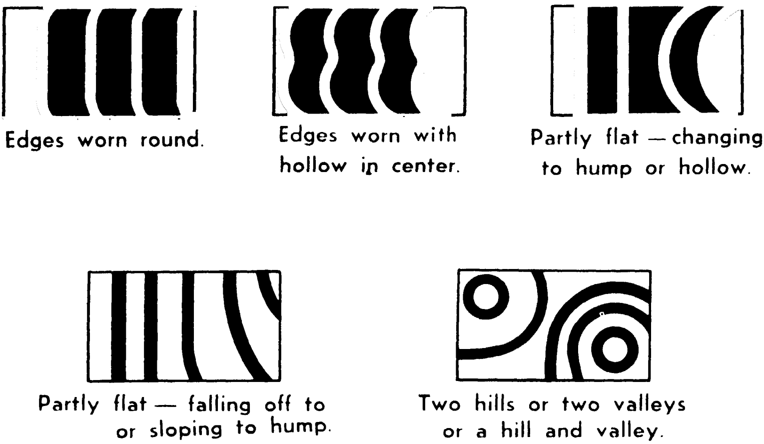


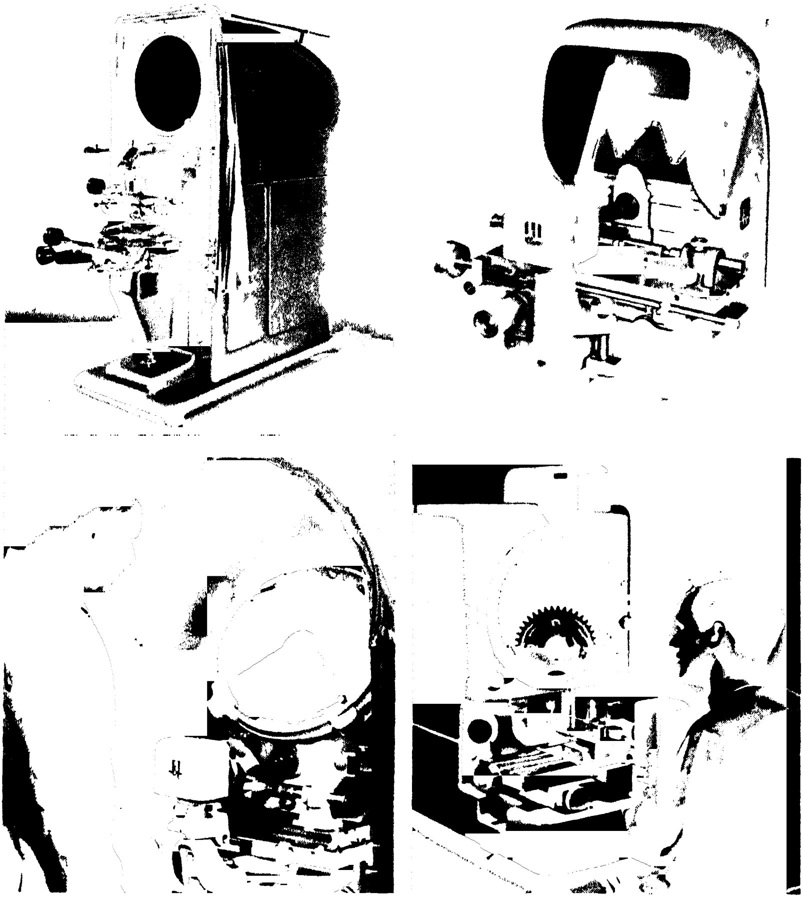
Fig. 11. Some of the patterns formed by interference bands and their interpretation.

Where the inspector's work calls for a great deal of exacting work and checking with optical flats on a variety of equipment, he would do well to supplement the description just completed with further study of catalogues, instruction books and other literature issued by the manufacturers of optical flats.

Optical Comparators

An optical comparator, so-called, is an apparatus for projecting the enlarged shadow of the profile of an object or workpiece on a ground glass screen. The image seen is usually a silhouette, but may be a detailed image. On the whole, an optical projector is a bulky piece of apparatus because space or distance is needed in order to enlarge or "blow up" the object optically; however, bench models for enlarging or magnifying and silhouetting small parts are available. Figure 12 shows a few of the commercially available models, including one which shows a detailed image of the workpiece.

Whatever its overall size, the optical comparator uses many of the principles and attachments found on the toolmakers' microscope. It is usually equipped with a "table" which can



Courtesy of Bausch & Lomb Optical Co
Courtesy of Jones & Lamson Machine Co
Courtesy of Eastman Kodak Co

Fig 12 Some of the commercially available optical comparators.

be moved from side to side or laterally, and from front to back. It can also be readily elevated or lowered as well as revolved like a turntable and tilted at an angle, all within certain limits, of course. With such facility, the object or workpiece can be moved into position so that its silhouette will take the desired position on the screen. By one means or another — micrometer screw and thimble, indexed elevating screw scale, protractor scale, precision gage blocks or an indicator — the movement of the workpiece clamped to the table can be measured or registered.

The comparator screen is frequently provided with cross hairs so that, as on the toolmakers' micrometer, the movement of the workpiece from, say, one edge to another can be registered. Separate translucent plates with templates and outlines etched on them can be clamped on the comparator screen so that the outline of the workpiece profile can be compared with a pre-established model.

Some models are equipped with a selection of magnifying lenses so that the image on the screen may be projected as 10, 20, 50, or more times the size of the original object. A study of the optical projection and reflection "circuit" shown in Fig. 13 will help in understanding the optical comparator.

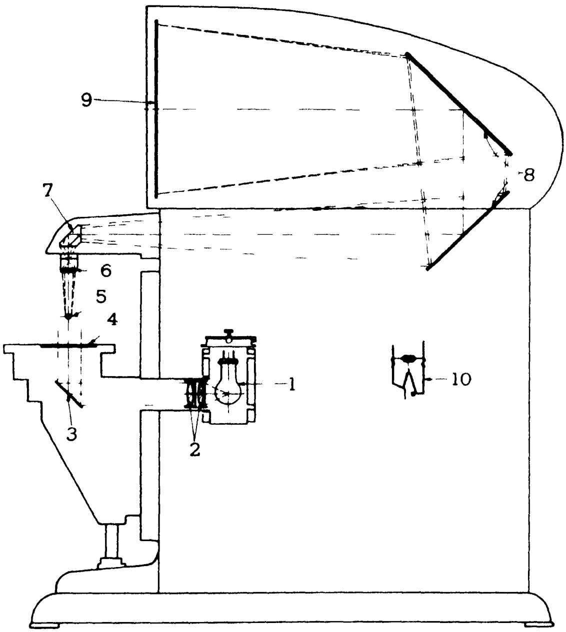
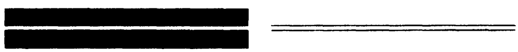


Fig. 13. Schematic diagram of the optical projection and reflection "circuit" of an optical comparator.

Final detailed instructions in the use of an optical comparator can be best gained from reference to manufacturers' instruction books or from experienced users. While the several available commercial makes are much alike, basically, each has its mechanical and adjustment peculiarities. Manufacturers' pamphlets also offer many suggestions for practical

uses of optical projectors, prominent among which are, of course, checking of screw thread and gear tooth form and angle, thread lead, gear pitch, gear, hob and cutter form, tool form, hole centers, and a great variety of special profiles.

There are some profiles on workpieces whose conformance to specification is practically impossible to measure by any other system than to have a draftsman carefully lay out the greatly enlarged facsimile on a translucent screen and then project an image of the workpiece, which has been enlarged to the same size, on the screen for comparison. Other shapes are measurable by other mechanical means, but the process may be infinitely slow in comparison to the speed and facility with which the optical comparator will do the job.



Courtesy of Optical Gaging Products, Inc.

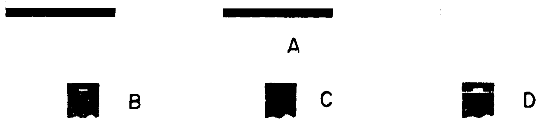
Fig. 14. Diagram shows ease with which space between two wide black bands can be discerned as compared with same width of space between two narrow lines.

Optical Gaging Charts for High Accuracy

Considerable progress has been made in the design and production of charts for accurate gaging with optical contour projectors. Charts are now produced by a scribing process for which accuracy is claimed to be within 0.0002 inch over the entire chart area. This would mean that for an image or shadow that has been magnified by ten, the error in terms of actual size of the part would be 0.00002 inch while at 50 magnification, it would be only 0.000004 inch. Thus, chart errors need no longer be a significant source of inaccuracy in optical gaging.

For very close tolerances, a unique method of arranging chart tolerance limits, known as "the optical bridge," enables an operator to detect as little as 0.0001 inch variation in a part even at a viewing distance of several feet from the projector screen. Selective grading is readily accomplished by using a special arrangement of chart lines which designate the amount by which the part is under or over the prescribed tolerances.

The basic feature of the optical bridge is the ease with which a band or "sliver" of light can be detected between a rather wide black gaging line and the edge of the projected shadow profile. This is illustrated by Fig. 14 in which two wide black

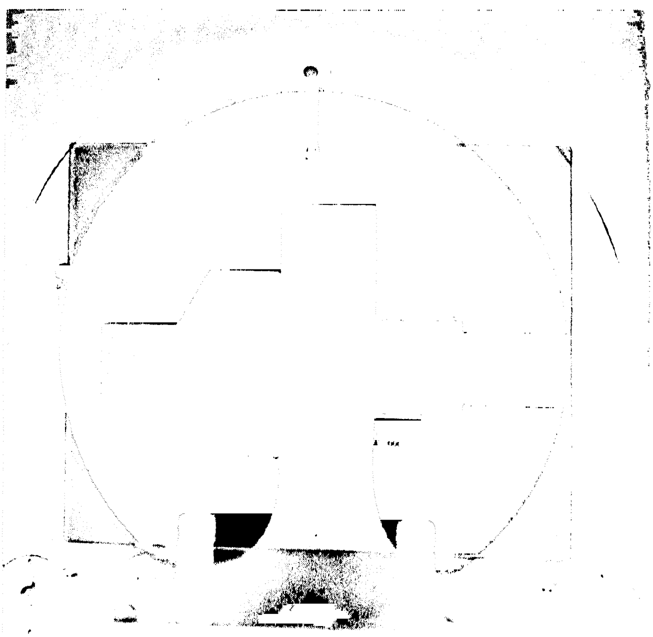


Courtesy of Optical Gaging Products Inc

Fig. 15. (Above) Special design of gaging line for optical comparator use. (Below, left) If enclosed light is seen within bridge, part is within tolerance limits. (Below, center) If no enclosed light is seen within the bridge, part is oversize. (Below, right) If light is seen beneath footings of bridge, part is undersize.

bands and two narrow lines are shown with the same width of space between them. A gaging line, known as the Micro-Gage* Bridge Line, is shown at A in Fig. 15. If even a sliver of light is seen within the bridge, as at B, it denotes that the part is within tolerance limits. If no light is seen within the bridge, as at C, the part is oversize. If light is seen beneath the footings

*Trade name, Optical Gaging Products, Inc., Rochester, N. Y.



Courtesy of Optical Gaging Products, Inc

Fig. 16. Correct size parts will show a pattern of lighted rectangles as along right hand edges of this shadow profile.

Courtesy of Optical Gaging Products, Inc.

Fig. 17. This row of accurately positioned alternate rectangles provides a very accurate centerline. Top edges of lower rectangles and bottom edges of upper rectangles are exactly colinear. Any overriding of shadow profile above or below gaging edges of these rectangles is readily discernible.

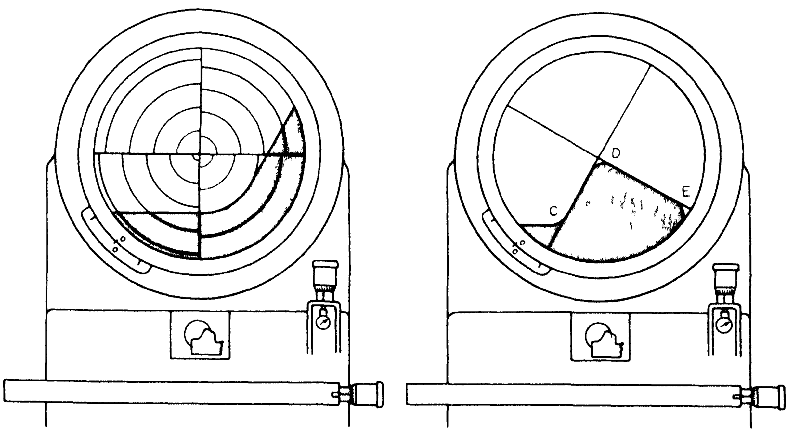
of the bridge, as at D the part is undersize. Correct size parts will show a pattern of lighted rectangles as in Fig. 16.

A row of accurately positioned alternate rectangles, as shown in Fig. 17, comprises a Micro-Gage centerline. The top edges of the lower rectangles and the bottom edges of the upper rectangles are exactly collinear. Any overriding of the shadow above or below the gaging edges of the rectangles is readily discernible and permits repeat readings to be made within 0.0001 inch.

A somewhat similar arrangement in which two broadened lines without the "bridge" openings have their gaging edges precisely located at the maximum and minimum angles is used for accurate gaging of small angular tolerances.

Locating Points in Space

Inspection difficulties frequently arise from the necessity of checking dimensions from points and lines not located on the

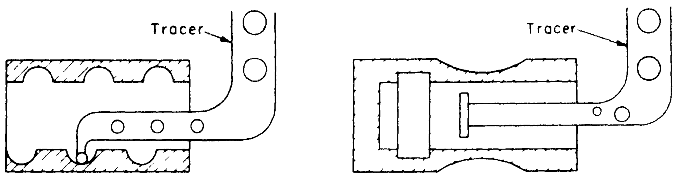


Courtesy of Eastman Kodak Co

Fig. 18. (Left) Standard radius chart being used to locate radius center of a fillet. Fig. 19. (Right) Standard centerline screen being used to find intersection D of sides CD and ED where corner is rounded.

surface of the workpiece, i.e. the centers of holes, the intersections of two straight lines which are the extensions of rounded corners, the radius center of a fillet, etc. The use of an optical contour projector greatly simplifies the task of inspection when these problems are present.

In Fig. 18 a standard radius chart is shown being used to locate the radius center of a fillet. In Fig. 19 a standard centerline screen is being employed to find the point of intersection D of sides CD and ED where a corner has been rounded. This same type of screen can be used to find the intersection of two lines joined by a rounded corner when they are not at right angles to each other. Full details concerning this procedure and also for finding the centers of holes and other similar problems can be found in the Eastman Kodak Pamphlet U-3 "Points in Space."



Courtesy of Optical Gaging Products, Inc.

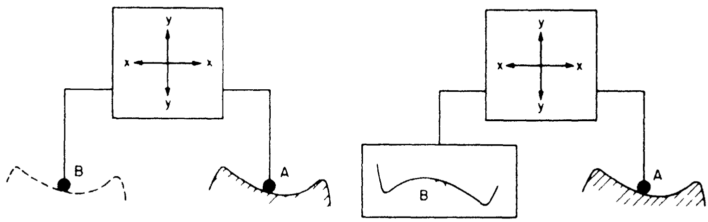
Fig. 20. (Left) Ball-tipped tracing stylus used to trace part contour where it is impossible to project it on the contour screen. (Right) Similar type of tracer unit using a disc-shaped stylus.

Checking Profiles that Cannot be Projected

Another problem now solvable with the aid of an optical contour projector is that of checking internal or hidden contours which are difficult or impossible to project on the contour screen. This is accomplished, as shown in Fig. 20 (left), by means of a special tracer unit. With this unit, a ball-tipped tracing stylus is moved over the part contour while an identical ball moves through an identical path and is projected on the screen. These two balls are connected by a pantograph arrangement which causes them to move in identically similar paths. Thus, a chart gaging profile can be placed on the screen and the path of the projected ball with relation to this gaging contour can be observed as the stylus ball passes along the contour of the part. An interposer fixture which makes use of an interposing bar or lever, similar to that just described, permits

profiles of large workpieces that cannot be brought into the field of view to be gaged accurately. Other types of stylii, such as the disk-shaped one shown in Fig. 20 (right), are used depending upon the kind of internal contour that is to be measured.

Another adaption of this idea, which permits any desired magnification to be obtained on the screen, is to project a fixed reference circle which is drawn to the desired magnification of the tracing stylus ball. The chart gaging profile, known as a reticle, which is also enlarged to the same magnification is then moved along the fixed reference circle as the stylus moves over the contour being inspected. The essential differences between these two methods are shown schematically in Fig. 21. Note that in the second method (illustrated by the right-hand diagram in the figure) the moving chart profile is necessarily inverted.



Courtesy of Optical Gaging Products, Inc.

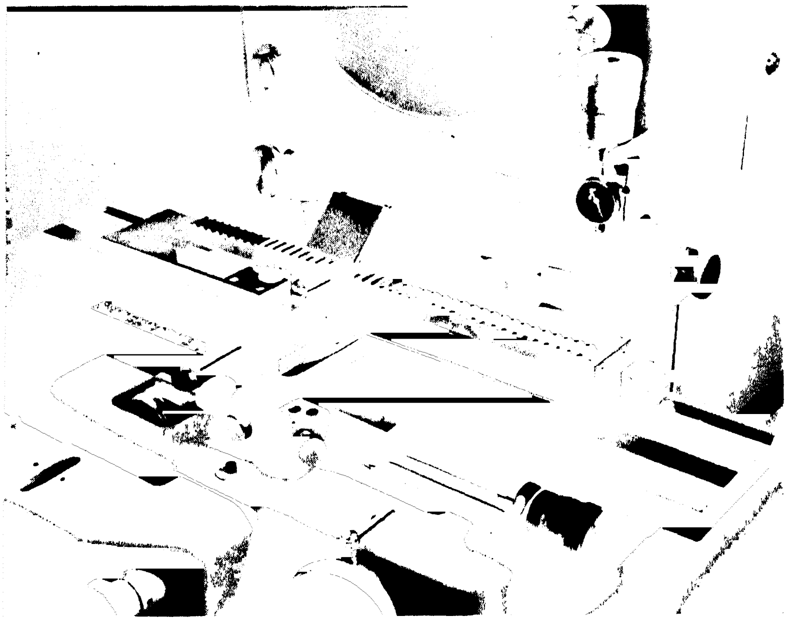
Fig. 21. (Left) Set-up where projected ball B moves over drawing of part contour for optical comparator gaging operation. (Right) Set-up where projection of accurately drawn part profile is moved over a fixed reference circle, as at B. Note that profile here is inverted as compared with that in the left-hand diagram at B.

The use of multiple-position fixtures which permit a part under examination to be moved in distinct steps of accurately known amounts is another way of handling the optical projection gaging of large work pieces. In Fig. 22 is shown a specially designed broach-locating fixture which permits the broach to be indexed across the path of the optical system in accordance with accurately positioned indexing notches.

A Sharp Image Is Required

The major difficulty in optical projection is to secure the true edge of the silhouette, to obtain a sharp image free from halation, aberration, fuzziness or double image. It is easy for

the shadow on the screen to be a sort of composite of silhouettes. An attempt has been made in Fig. 23 to diagram in exaggerated fashion what is meant by the possibility of double shadow in connection with a hole location problem. The silhouette on the screen may show rim *a* of a hole, for instance, or rim *a'*, or a composite of both and the operator may wonder as to which shadow edge to locate against the measuring hair line on the screen.



Courtesy of Optical Gaging Products Inc

Fig. 22. Specially designed broach-locating fixture which permits broach to be indexed across path of optical system for checking tooth form, spacing, and wear.

In any event, every effort should be made to so locate the workpiece on the table in the path of the projected light beam and to focus light and lens so carefully that double shadow, false silhouette edges and other aberrations are avoided as far as possible. If there is real doubt over the measurement secured on the optical comparator, if the tolerances are close, and if other suitable mechanical gaging methods are available or feasible, perhaps these should be employed as a check on or substitute for measurement by optical projection.

For both the toolmakers' microscope and the optical projector, good housekeeping is a prime requisite. Dust, moisture, oil, hair, fuzz, chips, particles, and what not readily collect on such apparatus. Too often they are left uncovered for long periods. More frequently they are as neglected as an attic room so far as keeping them clean is concerned. Rust and corrosion, scratches and digs, are as much taboo on the table, centers, vises and holding mechanisms as they are on surface

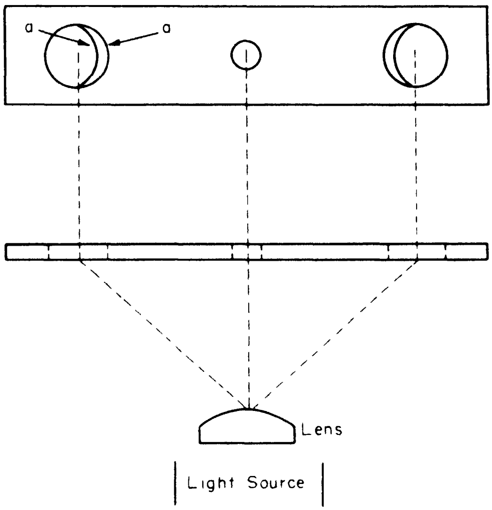


Fig. 23. The appearance of a double shadow in an optical projection hinders accurate measurements.

plate equipment. These instruments contain graduated scales — vernier, protractor, micrometer — and should receive the same care as any precision measuring instrument.

Alignment Telescopes and Auto-collimators

The highly successful tooling use of alignment telescopes and auto-collimators in place of wires, plumb bobs, transits and levels for accurate positioning of aircraft assembly jigs and accessories has led to their adoption for a number of other manufacturing purposes including checking and inspection.

The alignment telescope has an internal focusing optical system built into a tubular metal case, the external circumference of which is ground to be precisely concentric with the

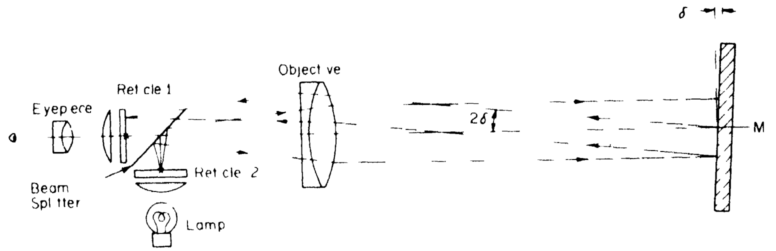
axis of the optical system. When this telescope is used in conjunction with a sighting target, it is possible to measure lateral displacements from an established line of sight with an error of the order of .003 inch at 120 feet or .001 inch at 40 feet. Furthermore, this highly accurate optical reference line is much more easily maintained and reestablished than a physical reference surface or a reference wire.

Figure 24 shows an alignment telescope with vertical and horizontal optical micrometer adjustments. By means of these adjustments the cross hairs in the telescope can be aligned with the cross hairs or other pattern in the target. Any vertical or horizontal displacement of the target from the line of sight can be read directly on the micrometer scales which are clearly visible in the eyepiece.

Courtesy of Farrand Optical Company Inc

Fig. 24. Alignment telscope with vertical and horizontal optical micrometer adjustments.

When the alignment telescope is used with a collimator, small angular displacements from an established line of sight are readily detected and measured. The collimator is a ground steel tube of the same diameter as the optical telescope and contains a glass reticle or target illuminated from behind and a lens system which causes the rays of light which pass through the reticle to leave the collimator in parallel paths. If the alignment telescope is aligned with the collimator so that the target pattern on the reticle is in view, any displacement of this target pattern as it is viewed against the cross hairs of the telescope will indicate an angular displacement of the collimator from the line of sight of the telescope. A scale may be provided on the reticle of the collimator to permit readings of the angular deviations.



Courtesy of Farrand Optical Company, Inc

Fig. 25. Diagram of auto-collimator showing that observed angle 2α is twice the actual angle of displacement α of the target.

An auto-collimator is shown diagrammatically in Fig. 25. In this instrument the illuminated reticle is within the instrument itself, hence only a mirror is needed as a target. An optical flat is used as the mirror. As shown in this diagram, when rays of light pass from the lamp through reticle No. 2, they are reflected by the beam splitter so that they pass through the objective lens and are projected as parallel rays to the mirror target. These rays are reflected back through the objective lens of the telescope and pass through the beam splitter to be viewed in the eyepiece. If the mirror target is not exactly at right angles to the optical line of sight of the auto-collimator, the reflected image of reticle No. 2 will be displaced from that which appears on reticle 1. As can be seen

Fig. 26. Checking fixture for rocket missile component in which seven auto-collimators are used.

in Fig. 25, the apparent angle of displacement (2A) is twice that of the actual angular deviation (A) of the mirror target from the perpendicular, a factor which improves the accuracy of measurement. By using an auto-collimator, targets can be aligned to the line of sight within an error of the order of one-half second.

Figure 26 shows a checking fixture on which seven auto-collimators are mounted for close range checking of a rocket missile component where extremely small angular tolerances are called for.

CHAPTER 12

Gaging and Inspection of Screw Threads

For the sake of brevity at this point it will be assumed that the inspector is well acquainted with the principles and elements of screw threads and the mechanical processes and methods which are used to produce nuts, bolts, screws, studs and tapped holes; that he has more than a casual acquaintance with taps, dies and chasers, as well as with turned threads, ground threads and rolled threads.

Few inspectors can avoid contact in some fashion with screw threads in a plant that performs machining operations on metal or plastic parts and any extra hours he spends studying threading techniques and screw thread elements will be profitable. Information and data on screw threads can be found in most mechanical engineering handbooks, and treatises on the subject are available in technical libraries. Inspectors could review profitably the contents of the Screw Thread Standards, Handbook H28, U. S. Department of Commerce, National Bureau of Standards, as well as American Standard ASA B1.1, Unified and American Screw Threads so as to be familiar with the data presented therein, for future reference.

Our concern here is with the suitable measurement and checking of screw threads to determine their conformance or non-conformance to specifications.

The Mating Part as a Gage

Possibly the most elementary method of measurement lies in the use of a so-called mating part. Years ago, you would see a nut of the proper size wired to the lathe where a man was turning a screw thread. Or hanging on the wall near any tapping operation would be a screw or stud which was judged to

be the proper size for checking purposes. If all the screws being cut fitted a certain nut, if a selected stud would readily run into the holes being tapped, that was all that was required. Even today, more often than might be suspected, batches of screws, nuts or tapped holes in workpieces are checked with some selected mating part. However, as will be seen, a much more exacting inspection is usually called for.

Factors to be Checked

The inspector should keep well in mind that there are several factors which will affect the assembly and proper fit of mating external and internal threads. Thus, in addition to the rather obvious visual defects of burrs or slivers and stripped, upset, rough, and malformed threads, measurements and checks are made of pitch diameter, major and minor diameters, lead, angle, and thread form. A less obvious visual defect, but important, is the so-called drunken helix. Then, too, the seemingly ridiculous circumstance may arise when the screw, stud or bolt, for example, has a $\frac{1}{2}$ inch-13 thread and the nut or tapped hole has been tapped with a $\frac{1}{2}$ inch-12 thread. A check of the number of threads per inch is all too often overlooked, ignored, or assumed.

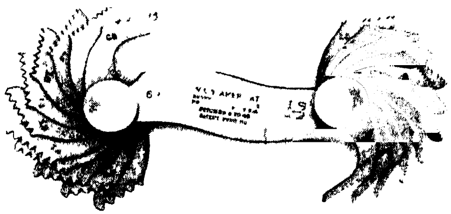
If a complete job of thread measurement is to be done, the following checks should be made in about the order shown.

Threads-per-inch count or pitch measurement.
Visual inspection for burrs, slivers, stripping, upset thread, and drunken helix.
Pitch diameter.
Major or outside diameter.
Minor or root diameter.
Lead.
Thread angle and form.

The test for thread count is simple. Lay a steel rule against an outside thread and count the number of peaks in 1 inch. Even better and faster is the use of a screw-pitch gage, a template such as is illustrated in Fig. 1. This type of gage is ordinarily necessary for counting internal threads.

Visual Inspection of Threads

The visual inspection of the workpiece thread, probably with the aid of a glass, should be one of the first steps in screw inspection although most people try to use a gage first and then stop to examine the screw to find out why it doesn't fit the



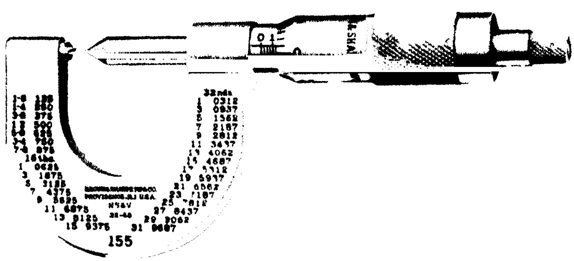
Courtesy of Brown & Sharpe Mfg Co

Fig. 1. Commercial type of screw pitch gage.

gage. In other words, get rid of the variables of dirt, chips, splinters, malformed threads or a drunken helix before wearing valuable metal off the ring gage or before deciding that the thread is oversize, tapered, or that lead error is present.

Thread Micrometers

For measuring or checking the pitch diameter of an external screw thread, a thread micrometer may be used. The end of the spindle of a thread micrometer is pointed as shown in Fig. 2 to a 60-degree cone for American Standard threads and an accurate 60-degree V is ground in the anvil. This anvil is free to rotate so as to adjust itself to the helix angle of the thread being measured. The sharp tip of the spindle point is ground off. Likewise, flats are ground on the peaks of the V and the root of the V is ground out or "cleared." This is done to make sure that only the pitch diameter is measured by the thread



Courtesy of Brown & Sharpe Mfg Co

Fig. 2. Screw thread micrometer.

micrometer and not the root diameter or major diameter of the screw thread. Before using a thread micrometer, screw the cone point of its spindle down into contact with the V-anvil and check the micrometer thimble's zero reading.

A thread measuring micrometer is designed to measure threads within a certain range of pitches. Thus, one thread micrometer may be used to measure the pitch diameters of threads in the range of 48 to 64 threads per inch while another thread micrometer is required to measure threads in the range of 8 to 13 threads per inch.

Since any given thread micrometer is required to measure a range of threads of different pitches, each of which may cause a slight variation of the anvil position on the thread, small errors in measurement are sometimes introduced. For this reason, the best procedure to follow in using a thread micrometer is to first measure the pitch diameter of a standard thread plug gage of the same size as the thread to be measured (if one is available), and to note the possible error. This error is then compensated for when checking the workpiece thread. As an example, suppose a batch of workpieces having a 1″-8 NC-3 thread was to be checked for pitch diameter with a thread micrometer and that the known pitch diameter of the available 1″-8 NC-3 thread plug gage was 0.9188 inch. If the thread micrometer measurement of the plug gage is 0.9183 inch, then the error of 0.0005 inch (0.9188 − 0.9183) must be added to the micrometer reading when a workpiece thread is measured. Thus, if the thread micrometer reading for a workpiece is, say, 0.9180, the actual pitch diameter is 0.9185 (0.9180 + 0.0005).

Classification of Thread Gages

Thread gages may be classified into two broad groups; in one group are the gages used to check the product and in the other are the gages used for reference. In the first group are the *working* gages which are used to check the product as it is being machined, and the *inspection* gages which are used to determine the acceptance or non-acceptance of the product. In the second group are the *setting* or *check* gages which are thread plug gages to which adjustable thread ring gages, thread snap gages, and other thread comparators are checked for size, and *master* or *basic* gages which are thread plug gages representing the physical dimensions of the nominal or basic size of the part.

In the first group of gages, the *working* gages are sometimes set to limits which are within the limits of the *inspection* gages. This practice assures that any part which is passed as being within tolerance by the working gage will also be passed by the inspection gage thereby reducing the possibility of a disagreement between the machine operator and the inspector in borderline cases, a disagreement which often arises when working and inspection gages are set to identical limits. The principle involved may be summarized by use of an analogy: If a 1″ ball fits into a 1.1″ hole, surely it will fit into a 1.2″ hole.

Working, inspection, setting and *master* gages differ with respect to the accuracy with which they are made. A *working* gage is made to the widest tolerances and is, therefore, the least accurate, while a *master* gage has the narrowest tolerances and is the most accurate. *Inspection* and *setting* gages lie in between. Gage makers manufacture gages to *working, inspection* or *master* gage tolerances, depending upon the intended application.

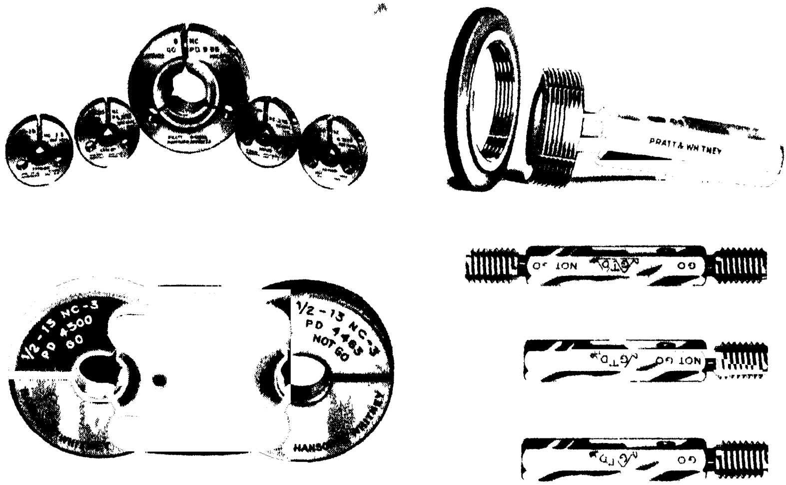
Screw thread gages are also classified according to accuracy as W, X and Y, the W being the most accurate. The dimensions and applications of each of these three classes of gages are covered in the National Bureau of Standards Handbook H28 (1944), Screw Thread Standards for Federal Services, and in American Standards B1.2, Screw Thread Gages and Gaging.

Thread Ring Gages

While a thread micrometer might be a natural first choice as an instrument for checking pitch diameter, in most shops thread ring gages are available and commonly used. The ring gage is the modern, wear-resistant, accurate counterpart of the old-fashioned nut hung by a wire on a machine. Illustrations of thread ring gages — also thread plug gages — appear in Fig. 3.

Basically, of course, a thread ring gage is just that — a single threaded ring. It can be a "Go" ring or a "Not-Go" or "No-Go" ring. As Fig. 3 indicates, thread ring gages are usually supplied in pairs. In most cases, a "Go" ring or a "Go" plug alone is insufficient for making a suitable check of the conformance of a screw thread, and the "Not-Go" member of the team also needs to be employed.

The first step in using a set of ring thread gages is to read the legend stamped on the rings. One ring should read "Go."

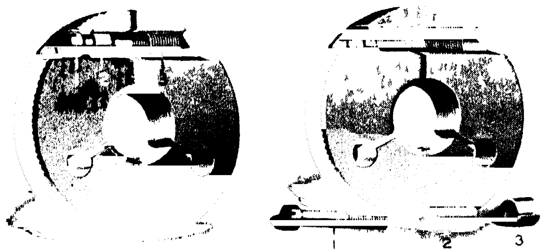


Courtesy of Colt Industries Pratt & Whitney Machine Tool Div
Courtesy of Hanson Whitney Co
Courtesy of Greenfield Tap & Die Corp

Fig. 3. Typical thread ring and thread plug gages.

The legend *should* give the thread size and pitch as, for instance, 7/16-20 NF, which, translated, means the workpiece should be 7/16 inch major or outside diameter; there should be 20 threads to the inch (National Fine Thread Series). The pitch diameter, upper limit, should be .4050 inch which should also be stamped on the gage. The "No-Go" member should show the same legend except that the pitch diameter (lower limit) would be .4024 inch. Sometimes the class of fit appears, but comparison of the pitch diameter tolerances with handbook thread tolerance tables will classify the fit. For example, the pitch diameter limits just mentioned are for a Class 3 fit. The gage legend should correspond to the work specifiations.

There is a strong tendency to assume that so long as a thread ring gage is on the job it is automatically an accurate gaging device. Where the shop systematically checks its thread gages as a routine or where the inspector is sure the gage has recently been tested, he can forego his own check of it, because the gage should withstand a number of gaging operations without appreciable loss of accuracy. Where this is not the case, the pair of rings should be checked on setting plugs if the inspector knows nothing of their history, career or existing condition. A setting plug is a very accurately made thread plug which is used to



Courtesy of Taft Peirce Mfg Co

Fig. 4. (Left) Assembly view of a thread ring gage. (Right) Ring gage with adjusting elements removed.

facilitate the adjustment of a thread ring gage to its proper pitch diameter. One such setting plug is required for each size of "Go" ring gage, and one for each size of "Not-Go" ring gage. These setting plugs, therefore, are used to control the accuracy of the ring gages which are used to check external threads.

Because of three radial slots — one of them a through slot — cut into the body of the thread ring gage, see Fig. 4, the effective pitch diameter of the gaging section can be reduced or increased within a restricted range (from .002 inch on small sizes to .010 inch on large rings). The assembled view in Fig. 4 illustrates how this can be done. Turning screw No. 3, pushes the head of the precision ground sleeve No. 2 against the shoulder in the left hand segment of the gage and tends to open or spread the gage. Unscrewing No. 3 reverses the action and withdraws the sleeve. When screw No. 1 is tightened, the gage segment shoulder is tightened against the sleeve No. 2 while, simultaneously, the split screw No. 3 expands in its tapped hole and the whole mechanism clamps in position.

In most shops, a gage that has been suitably checked and set on a correct setting plug is officially "sealed" by pouring wax in the two adjusting screw holes. Where such a system prevails, an inspector should at least suspect and probably not use a thread ring gage if either or both of these wax seals are missing. Workers and others without authority frequently set thread ring gages to suit some particular circumstance or variation of their own.

Setting an Adjustable Ring Gage

The technique of setting or checking a thread ring gage by means of a setting plug involves one or two peculiarities of its

own. In terms of fingertip gaging pressure, the setting plug should screw into the ring all the way so that the end of the plug is flush with the face of the ring gage under certainly not less than ½-pound pressure nor with more forcing than, say, 2 pounds. It is not necessary to "wring" a setting plug in. However, in screwing the plug in, there should be no local binding, catching, hanging up, chatter nor grating of metal surfaces. A slight surfacing of the ring gage threads with thin oil is permissible. With the setting plug in position, try the gage thoroughly for a snug fit; try to rock it and particularly note if any movement occurs when longitudinal or end thrust is applied. If the ring gage is being adjusted to the correct pitch diameter, test the setting with the master plug after the ring's clamp screw has been finally tightened up. (The master plug is an extremely accurate gage which is used only for checking, never for setting, a ring gage.)

It goes without saying that setting plugs should be used as infrequently as possible and should be checked for size practically every time after use. Where wear up to .0001 inch to .0002 inch is detected, the setting plug should be discarded. (Sections farther on describe the three-wire method of checking setting and master plugs.)

Proper Care and Use of Thread Ring Gages

While the radial slots in a thread ring gage form natural, so-called dirt grooves which tend to clean the threads of a workpiece, it is wise to clean the screw being measured so that it is free from grit, chips or sludge. The ring itself should be frequently purged in solvent, kept coated with a rust-preventive when in storage and in general treated like a precision gage. If not set down on its face, a thread ring gage will readily roll off a machine or bench. If this happens, check it again on its setting plug; the blow may have distorted it or changed its original setting.

Don't use a ring gage as a paper weight, convenient tack hammer or as a vise to hold a workpiece. Its radial slots make it, in effect, a threading die and many workers perform the criminal act of using the gage to size their defective work. If more than the customary two pounds gaging pressure is required to screw a thread ring gage on a workpiece, consider the screw thread oversize, defective in some respect, and reject it. Some shops have a rule that a ring gage may bind

over the first thread or two on the assumption that the first or lead thread on a screw may be slightly malformed. If the ring goes part way on the screw and then begins to bind, consider the possibility of taper in the screw or a lead error. Incidentally, be sure the legend on a thread gage corresponds with the screw specifications before rejecting a sample workpiece. It is easy to attempt to gage a ½″-13 thread with a ½″-12 gage.

A thread ring gage cannot ordinarily be used to analyze the individual errors present in a screw. If the pitch diameter is oversize, the ring will not engage, of course. Neither will it turn on over an oversize major diameter. If the minor diameter is "off" if the screw teeth roots are filled with dirt or filleted from a worn die or lathe tool, the gage will bind. Excessive screw-thread lead error, like taper, will ordinarily be detected after a few turns of the ring gage. Where very fine threads are being gaged, care must be exercised not to "cross thread" the ring gage on the screw.

Some people do not wind a watch or an alarm clock by turning the winding stem. No, they hold the stem and turn the clock. The same thing is unconsciously done with a ring gage. On the whole, it is better to hold the gage firmly and screw the workpiece into it. A more accurate, a more delicate test is secured and much less wear is ordinarily imposed on the gage. If, however, the workpiece is large and heavy, the reverse rule prevails.

How "Not Go" Gage Checks the Pitch Diameter

A major or minor diameter may be undersize to a limited extent and not affect the assembly of the screw or possibly not affect its strength in use enough to count, but a pitch diameter must be "on the button," within tolerances, and certainly not undersize. Hence the "Not Go" gage. Figure 5 shows the main difference in thread form between the "Go" and the "Not Go" thread gages. The "Go" gage will be affected by conditions other than pitch diameter variations. Its roots only are "cleared." But on the "Not Go" member not only are the roots cleared, to a greater extent than in the "Go" member, but also the peaks of the gage threads are purposely truncated. The intent is that the "Not Go" member shall check pitch diameter only and be unaffected by these other conditions.

If a screw thread will enter a "Not Go" ring thread gage by more than one turn and a half, the pitch diameter of the thread being tested is considered undersize.

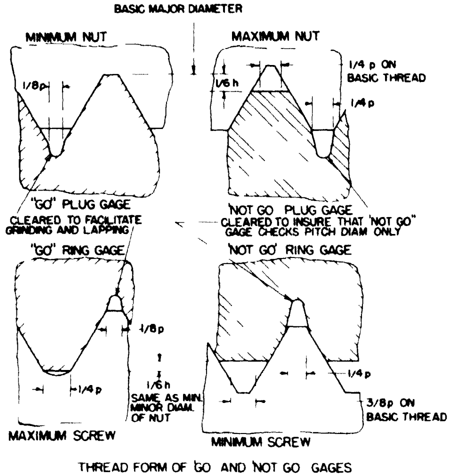


Fig. 5. Thread form of "Go" and "Not Go" gages. The "Not Go" gage checks only the pitch diameter.

Ring-gage accuracy can be affected by temperature variations. With many threaded pieces to be checked, the tendency is to hold the ring gage in the hand for a long, continuous period so that its temperature is raised appreciably. This could be avoided by holding the gage in a vise or stand.

Thread Plug Gages

The subject of the mating-part type of gage is naturally not complete without taking up thread plug gages. This is a single purpose type of gage — one gage to a size — and it is not subject to adjustment at all. More so than a ring gage, a plug gage must be made for a specific thread size, class and tolerance. A plug gage with "Go" and "Not Go" member tolerances for Class 1 threads, for instance, is of no use for Class 3 fits. Wear cannot be compensated for by adjustment, the gage must be replaced after it has worn down several "tenths," though some plants renew them temporarily by chrome plating them ostensibly back up to size.

In general, the same rules apply to the care, maintenance and manipulation of plug gages as for ring gages. The "Go" plug ring gage should be screwed in to full engagement with a gaging pressure not exceeding two pounds. The "Not Go" end must not enter more than a turn and a half, else the tapped hole is too large. The plug gage may reject pieces

for variations in pitch diameter, major and minor diameter and lead error or for combinations of these, but provides no basis for analyzing the cause.

Although most thread plug gages are provided with dirt grooves, where precision measurement of tapped holes is required, it is preferable that the holes be thoroughly clean and that the gage shall not have dirt grooves. The grooves have a tendency to make the gage act like a hand tap and to size the work. Also, if dirt grooves are absent, the touch or feel of gaging is more sensitive.

One other too common practice with thread plug gages should be avoided. Where the work being tapped is held in a lathe chuck, some workers fail to wait for the motion of the machine to cease before introducing the gage. They want the machine to wind the workpiece up on to the gage. But this is not gaging; all sense of feel is lost.

While it is better to introduce the workpiece to the ring gage, the reverse is true of the plug gage. If you will imagine yourself handling a pencil (except in the case of the big diameter double-handled thread gages) you will probably do a more satisfactory job of measuring.

As will be seen in a section or two farther on, other types of external thread measurement apparatus can well be used in place of the ring gage, but up to this time no better general instrument than the thread plug gage has yet been devised for checking internal threads. One or two types of indicating gages are available, but they must generally be used on hole sizes above 1¼ inches.

Roll Thread Snap Gages

One of the objections to the ring thread gage, is that the thread size cannot be checked while the workpiece is between centers in the machine. To overcome this difficulty, thread snap gages of the type illustrated in Fig. 6, have been devised; another name for them being *roll* thread snap gages.

The gage "jaws" are really pairs of free-turning rolls which also have lateral freedom or play. There are two sets of rolls: a "Go" pair and a "Not Go" pair arranged in the conventional manner of the ordinary "Go" — "Not Go" snap gage. The "Go" roll width — short or long — usually compares with the average length of engagement of the screw threads to be measured. The thread forms on the rolls are annular rings.

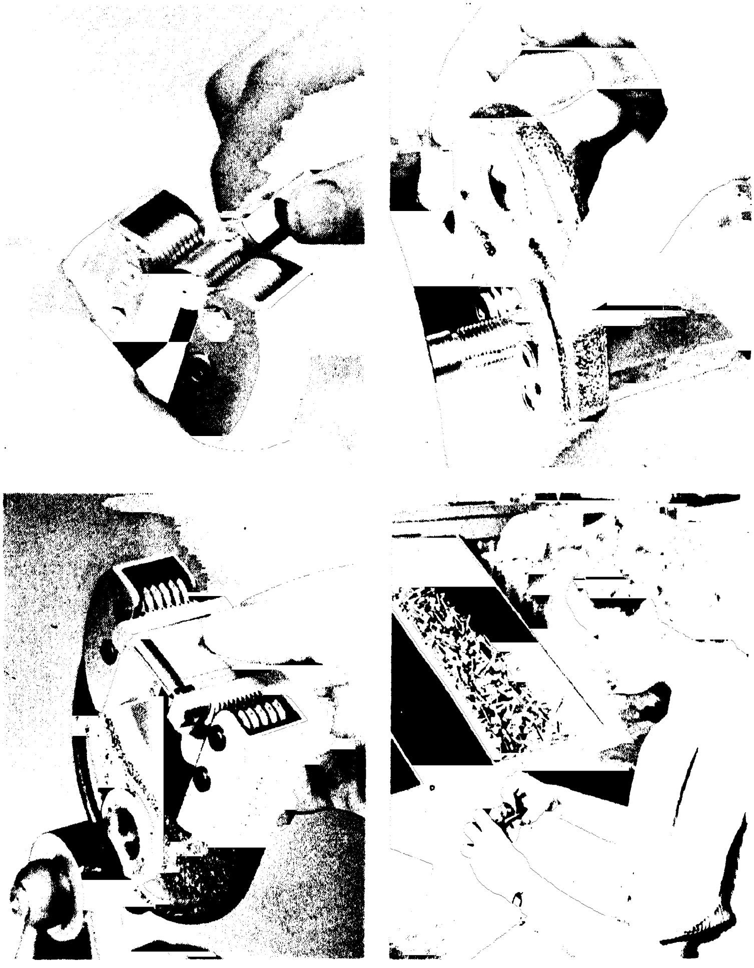


Fig. 6. Roll-thread snap gages shown being checked with combination gage block master, with a setting plug, and being used for gaging workpieces in and out of the machine.

In other words, the rolls are not cut in a helix like a screw thread.

The ribs of the "Go" rolls have the full thread profile and also some root clearance whereas on the "Not Go" rolls they are truncated and have extra root clearance so that the "Not Go" rolls check only the pitch diameter as shown in Fig. 5.

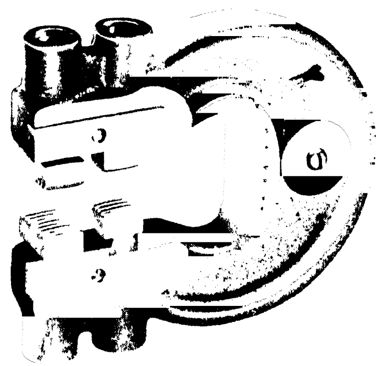
The major attribute of roll snap thread gages is their ability to get at work in the machine. They are also much

faster to use for checking a batch of workpieces because the inspector does not have to slow down to screw the workpiece into the gage to full engagement as in the case of the ring gage.

Their major drawback is the ability of the rolls to "roll" literally over a slightly oversize workpiece. For this reason, the recommendation is often made that they be deliberately set from .0002 to .0005 inch undersize. No more than a pound of fingertip pressure should be used in gaging the work, otherwise oversize pieces will surely be passed. Roll thread gages will not readily catch excess ovality in the workpiece unless the inspector takes the trouble to revolve the workpiece in the gage jaws for this purpose.

Other Types of Thread Gages

A variation of the roll snap thread gage appears in Fig. 7, a snap gage whose threaded anvils are rigid but adjustable to a setting plug. While a gage like that shown in Fig. 7 *looks*



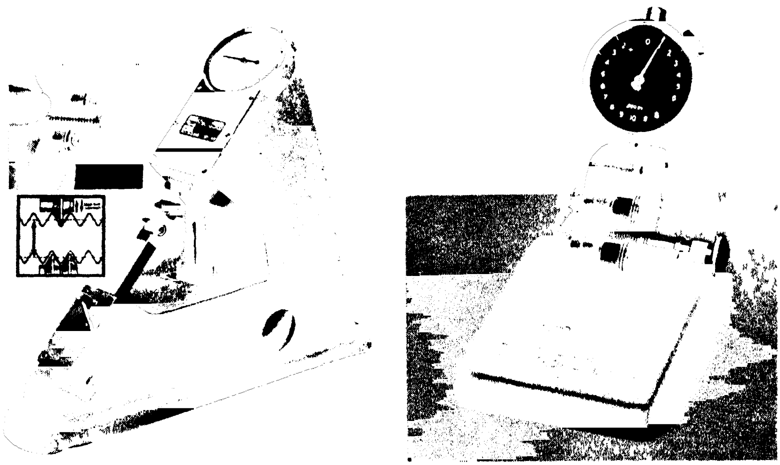
Courtesy of Taft Peirce Mfg. Co.

Fig. 7. Thread snap gage in which the threaded anvils are rigid, but adjustable to a setting plug.

very satisfactory, it must be used expertly. The anvils are really segments of threads ground with the proper helix angle on cylinders of large diameter. In making the measurement with such a gage, it must be canted or twisted a little — juggled just a trifle on the workpiece threads — to align it with the workpiece thread helix angle.

The solid-jaw thread snap gage is subject to very ready wear. Its setting should be checked frequently.

The ribbed roll idea has been applied to indicating type gages of the sort shown in Fig. 8. In the type of gage at the left, a single ribbed roll is used on the upper or sensitive (measuring) contact and a double ribbed roll on the lower, solid, reference anvil. The tooth form of the ribs is somewhat truncated and the roots and the bottom of the flanks are "cleared" or ground back so as to make sure that the gage's reading will be affected by nothing more than variations in workpiece pitch diameters. In the type of gage at the right,



Courtesy of Federal Products Corp

Courtesy of Colt Industries Pratt & Whitney Machine Tool Div

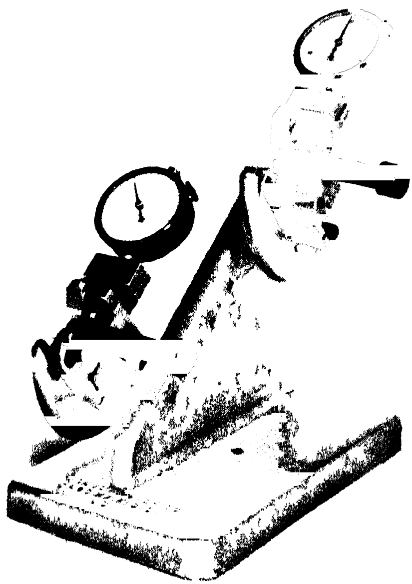
Fig 8 Indicating types of thread comparators used for checking external thread pitch diameters. Initial setting is established with a setting plug

three rolls are used. The two lower rolls are mounted in a stationary position, while the third roll, mounted on a preloaded armature, is swung into contact with the work piece. The comparator shown has two-rib rolls for checking pitch diameters only, but the same type of gage is also available with multi-rib rolls for checking cumulative errors in lead, angle, and pitch diameter.

The indicating thread gage is mastered on a suitable basic or master thread plug gage. The trick in mastering it and in using it subsequently on workpieces is to be sure the back stop is set at the proper height, angle and depth so that the pair of gaging thread rolls contact on the true diameter of the workpiece and not on a chord. As usual, the back stop can be positioned by watching the gage's indicator as the master

is manipulated between the rolls. The indicator's maximum reading denotes the proper position for back stop setting.

Still another fast, accurate, method of checking external threads makes use of the type of gage illustrated in Fig. 9. This upper gage is essentially a functional ring thread gage split in two halves or segments which pivot on studs. The segments literally wrap around the workpiece thread and the indicator



Courtesy of Johnson Gage Co

Fig. 9. A pair of indicating-type gages mounted for "Go" and "Not Go" inspection of a screw thread

shows the comparison between the workpiece and the setting plug with which the gage is mastered. Actually, the indicator reading is the "assembly size" of the screw. The lower gage (comparator) checks the pitch diameter only. The elements are annular single ribbed cone and vee rolls with profile for "Not Go," flank contact only. The lower pair of rolls is mounted on a pivoting cradle for maximum ease and speed of operation.

An additional advantage of indicating type thread gages is their ability to detect out-of-round and taper conditions if the piece is rotated and moved longitudinally. A tapered screw with a maximum pitch diameter that is within tolerance but

with a pitch diameter at the other end of the taper that is undersize, may produce an undesirably loose fit in a straight tapped hole especially under strain or vibration.

Checking Tapered Threads

Screws and nuts with deliberately tapered threaded sections are sometimes encountered. Pipe fittings form the most common example. In considering the measurement of extreme tapered threads the inspector needs to keep the geometry of tapers in mind. Two of the dimensional variables of a taper must be known by measurement before its conformance can be determined.

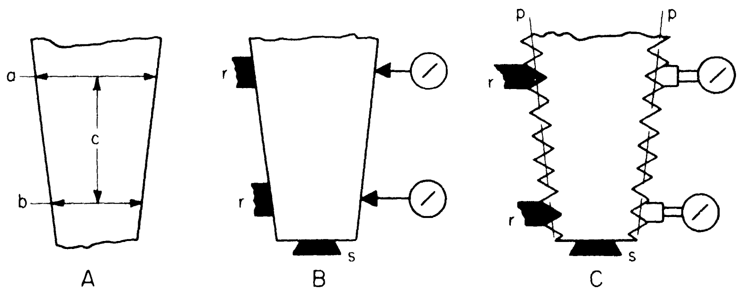
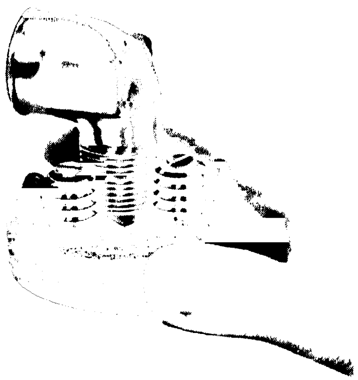


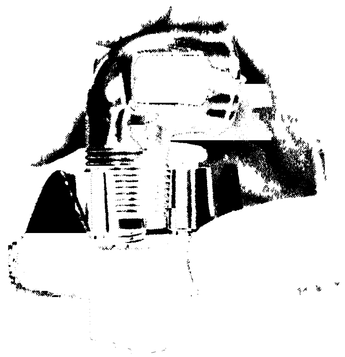
Fig. 10. The same geometry that applies to the measurement of plain tapers is used in the measurement of tapered threads.

What is meant appears, as review, in diagram A of Fig. 10. If diameters *a* and *b* are known and length *c*, then the amount of taper is known. An indicating gage can of course be "mastered" with a correctly tapered piece, its reference anvils *r* and *r*, see Fig. 10-B, and its indicators properly set with the master against a suitable stop *s*. The indicators will then register the deviations of the workpieces from the master.

The same geometry applies to threaded tapers if it is remembered that the pitch lines, *p* and *p* of sketch C, are used for checking the taper. Indicating gages can be made to perform the function hinted at in sketch C. Tapered threads also can be checked by the three wire method — see farther on.

A common and suitable gage for checking tapered threads appears in Fig. 11-A, a gage with a suitable reference stop or base and with triple rolls whose thread ribs are made on a suitable taper. The major diameter or outside diameter is similarly checked by a gage with three tapered rolls which





Courtesy of Colt Industries, Pratt & Whitney Machine Tool Div.

Fig. 11. (A, left) Roll-type gage for checking tapered threads. (B, right) Roll-type gage for checking the major diameter of a tapered thread.

make contact only with the crests of the workpiece thread as shown in Fig. 11-B.

Ring thread gages are also made with suitable internal tapers. The technique is to turn the ring gage onto the tapered thread until the face of the gage is flush with the end of the threaded piece. If the gage will not turn flush, the workpiece is oversize; if the ring gage sinks below flush under normal gaging pressure, the workpiece thread and taper are undersize.

The same technique is used for gaging internal tapered threads with a tapered plug gage. The gage has a flat ground in it and/or scribed lines. The gage should screw in just to the mark in a properly tapered tapped hole.*

Aside from the plug gage, the inspector has no other means of checking tapered threaded holes except by making a plaster of Paris or sulphur cast of the hole (a technique about to be described) and checking this cast with an optical comparator. If the tapered hole is of large enough inside diameter, indicating gage equipment can be designed to solve the problem.

* Where the inspector works in a shop making more or less of a specialty of tapered threads as, for instance, on hose couplings, pipe fittings, "dry seal" joints and the like, he should make a special study of the subject in the Bureau of Standards Screw Thread Handbook (H28, 1944) and in the applicable American Standards Association publications.

The method of making plaster of Paris casts is fairly simple. Lightly coat the internal thread with oil or grease. Make up the usual thick mixture of plaster of Paris and water and tamp it thoroughly into the tapped hole. If the hole is large enough, insert a pair of wires or a thin steel strip into the soft plaster to reinforce the cast and to provide a means for unscrewing it when hardened. A little practice will indicate how to get casts without cracking or crumbling them plus obtaining sharp, accurate impressions of the internal threads. The cast can then be used like an external thread for various measurements and observations.

Three-Wire Method of Thread Measurement

The fundamental standard method for checking the pitch diameter, taper and ovality of externally threaded pieces, including setting plugs and plug thread gages and casts of internal threads, is the "three-wire method." Knowledge of the measuring-roll technique for taking measurements on tapered parts facilitates an understanding of the geometry behind the three-wire system.

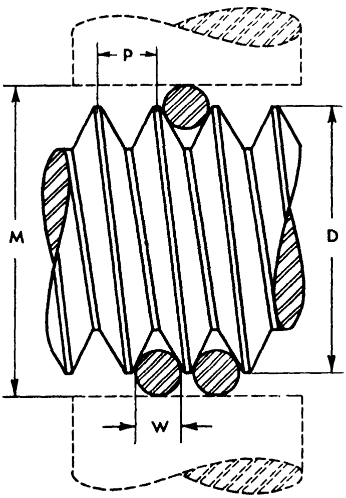


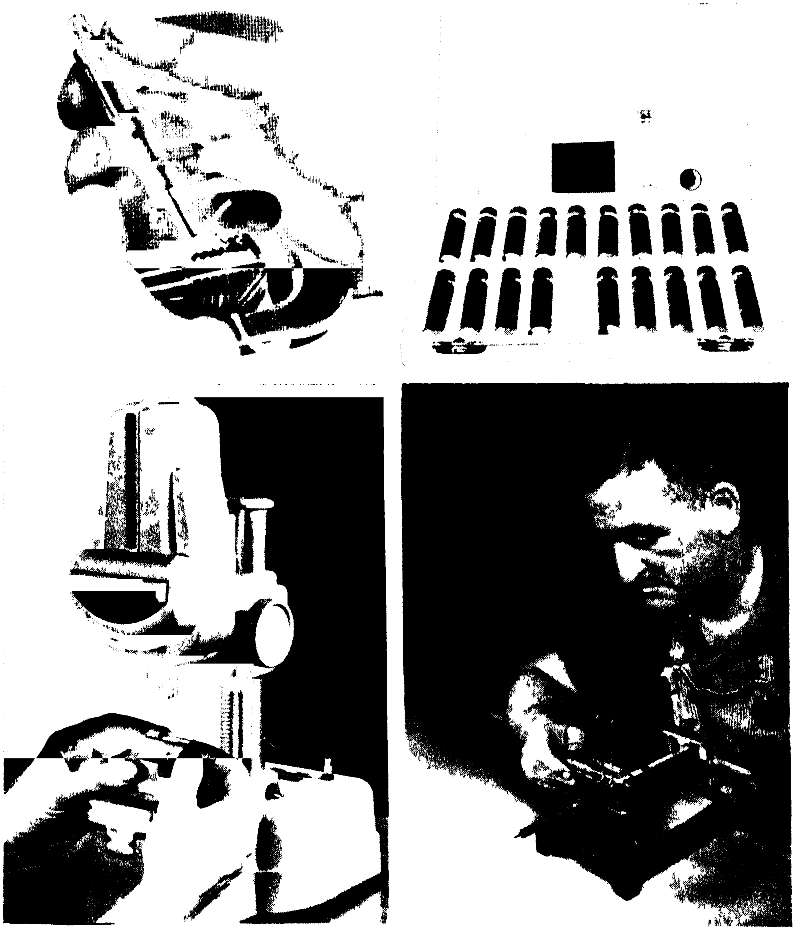
Fig. 12. Method of checking pitch diameter by the three-wire method.

The pitch diameter may be checked very accurately by this method. It is especially useful in checking very accurate work, such, for example, as thread gages. It usually would not be employed in checking parts in connection with ordinary manufacturing practice because thread gages require much less time and are preferable for shop measurements. The three-wire method, however, is so generally used for precision work that it should be understood. Three wires or pins of the same diameter (within very close limits) are placed in contact with the screw thread, as illustrated by the diagram, Fig. 12. Two wires are placed in contact with the thread on one side and a third wire on the opposite side. When the micrometer is in contact with all three wires, this insures measuring perpendicular to the axis of the

screw thread. The following simple formula is for determining what the pitch diameter of the American Standard screw is for a given measurement M:

$$\text{Pitch diameter } E = M + (0.86603 \times P) - (3 \times W)$$

where P is the pitch of the thread and W is the pin diameter. As an example, assume that a 2½-inch American Standard screw thread (Coarse-thread Series) has a measurement M



Courtesy of Sheffield *Courtesy of The Van Keuren Co* *Courtesy of Federal Products Corp*

Fig. 13. Some of the measuring devices used in the three-wire method of measuring pitch diameters.

over the wires of 2.556 inches, using wires of 0.1443-inch diameter. What pitch diameter does this measurement *M* represent? Applying the formula, we have

$$E = 2.556 + (0.86603 \times 0.25) — (3 \times 0.1443) = 2.3396$$

Similar three-wire formulas for the measurement of other forms of screw threads such as Acme and British Whitworth are given in standard handbooks.

If this screw thread is in the Class 3A Series the maximum pitch diameter is 2.3376 and the minimum 2.3298 inches; hence, in this case, the formula shows that when measurement *M* is 2.556 inches, the pitch diameter is 0.002 inch larger than the maximum allowable pitch diameter of 2.3376 inches.

Measurement *M* over the wires may be made by using an ordinary micrometer. Special measuring fixtures of the micrometer type have also been developed for use with the three-wire method. These fixtures provide convenient means of holding the wires in position and the micrometer is mounted so that it can move freely either parallel or perpendicular to the axis of the screw thread which is held in a horizontal position between adjustable centers. Some of the measuring services used are shown in Fig. 13.

Determining the Wire Size

In checking screw threads by the three-wire method, any wire diameter *W*, Fig. 12 may be used provided the wires are small enough to enter the thread and contact with the sloping sides and are large enough to project above the top or crest of the thread, thus permitting proper contact with the micrometer or other measuring instrument. It is preferable, however, to use wires of the size required to make contact at the pitch line or mid-slope of the thread, because then measurement of the pitch diameter is least affected by any error in the thread angle. The term "best size" is commonly applied to wires making pitch-line contact.

To determine the best size wire, divide one-half the pitch by the cosine of one-half the included thread angle in the axial plane or by the cosine of 30 degrees for an American Standard thread form. The best size may also be obtained by multiplying one-half of the pitch by the secant of one-half included thread angle. For the American Standard or other

60-degree threads, this rule may be simplified as follows:

Best size wire for American Standard = 0.57735 × pitch

Effect of Lead Angle on Three-Wire Measurements

If the lead angle is large as in the case of many multiple screw threads such as are found on worms, quick-traversing lead-screws, etc., the ordinary rule or formula for checking the pitch diameter by the three-wire method is inaccurate and the effect of the lead angle on the position of the wires should be taken into account. This effect depends not only upon the size of the lead angle, but to some extent upon the degree of accuracy required in checking the pitch diameter. The formula given is sufficiently accurate for practically all three-wire measurement of standard 60-degree single-thread screws which have lead angles not greater than about 4½ degrees. (The error in measurement M is about 0.0005 inch when the lead angle is 4½ degrees.) For lead angles, above 4½ degrees, formulas which compensate for the effect of lead angle on the wire measurement should be used. Such formulas may be found in standard handbooks and reference works.

Pitch Diameter Measurement of Drunken Threads

When the thread is correct in form, either the thread micrometer or the three-wire method will give equally good results; but if the thread is not of the correct shape, but is "drunken," as indicated in the illustrations Figs. 14 and 15,

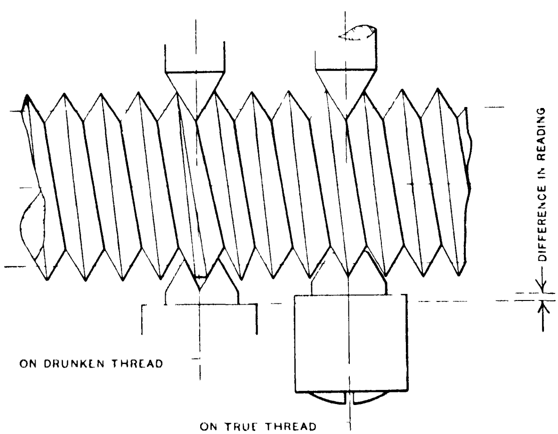


Fig. 14. The anvil type of thread micrometer gives varying measurements on true and drunken threads.

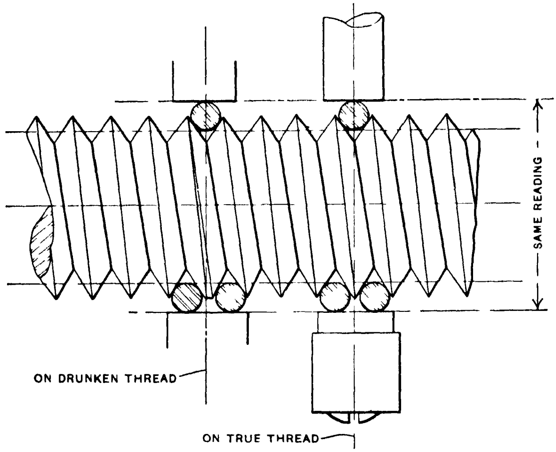


Fig. 15. The three-wire method of thread measurement makes no distinction between true and drunken threads.

then only the anvil type of thread micrometer shows this variation, while the three-wire method would not indicate any error, provided the thread angle is correct. This is because the three-wire system measures the grooves cut by the thread tool, which is always at the same depth and is unvarying in shape; hence, the error, if any, would not be detected. The same condition is met with in the ball-point micrometer. (See Fig.

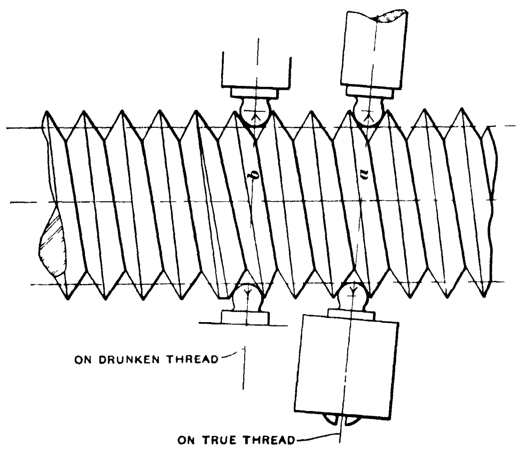


Fig. 16. The only difference in measurement on true and drunken threads made by the ball point micrometer is due to the very slight difference in inclination, too slight to be appreciable.

16.) The lower anvil point of a regular thread micrometer, however, since it spans the abnormal thread, as shown in Fig. 14, instead of making contact with the sides of the adjacent threads, indicates the irregularity by giving an increased reading for the pitch diameter.

This does not mean that the three-wire method of measuring pitch diameters is unreliable for ordinary use. With the methods used for accurate thread cutting in general, a drunken thread is seldom produced. If the thread is drunken, the thread micrometer will indicate this defect, but the three-wire system nevertheless measures the pitch diameter correctly under all circumstances, as the principle of its use depends on the bearing of the wire on the sides of the thread groove.

The ball-point type of micrometer (Fig. 16) is especially useful for comparing the pitch diameter of a tap or screw thread with that of a standard thread plug gage. Since the purpose is to compare pitch diameters instead of measuring them, an exact relation between the pitch and the diameter of the ball points is not necessary. An approximate relationship, however, is necessary, since the ball point must be small enough to enter the thread groove and bear on the angular sides. If the thread is an American Standard, the ball diameter for pitch-line contact is 0.577 × the pitch, but this diameter might vary anywhere from 0.6 to 0.8 × the pitch.

Accuracy of the Three-Wire Method of Measuring Screw Threads

It is possible to check screw thread sizes very accurately by this method; however, the degree of accuracy depends very much upon the accuracy of the wires used as well as the accuracy of the measuring instrument. The measurement may also be affected appreciably by the amount of contact pressure against the wires in measuring. If the accuracy of the pitch diameter of a screw thread gage is to be checked within 0.0001 inch by the wire method, it is necessary to know the wire diameters to within 0.00002 inch. Each wire should be round within 0.00002 inch and should be straight within the same amount over any quarter-inch section. A set of three wires should have the same diameter within 0.00003 inch; moreover, this common diameter should be within 0.0001 inch of the "best size" for any given pitch. As previously explained, the "best size," as it is commonly called, is one which makes contact at the pitch line or at one-half thread depth where

any errors in the thread angle will have the least effect upon the measurement over the wires. Tests made to show the effect of contact pressure were made by measuring a 24-pitch thread gage of the plug type. The measurement, with a contact pressure of 5 pounds, was 0.00013 inch less than with a pressure of 2 pounds. If proper precautions are taken regarding wire accuracy and contact pressure, it should be possible to check plug gages within an accuracy of 0.0001 inch. If the wire diameters are accurate to only 0.0001 inch, then the pitch diameter measurement is not likely to be more accurate than 0.0003 inch. This, however, may be accurate enough for many classes of work.

Optical Comparators

Within certain limitations, the optical comparator is readily used to check external threads. The shadow, the sharp silhouette of the thread on the projector screen can be compared with a fine line outline drawn on a supplementary glass placed on the main screen. An advantage of optical projection is the ability to observe outside diameter, pitch diameter, root diameter, form, thread angle, and lead error all at once. The disadvantage is the observer's inability to read and trust measurements where the tolerances are less than .0005 inch.

Indicating Gages

As has been said, the plug thread gage is about the only practical gage for the rapid checking of internal threads, especially on small holes. (At least an hour can be used up preparing a Plaster of Paris cast of a tapped hole and checking it either with three wires or by optical projection.) However, when the inside diameter is large enough, indicating gages like those pictured in Fig. 17 are very satisfactory. A master must be used, of course, and great care should be exercised to see that the gage is centralized. The criterion of correct measurement here would be repetition of readings. The contacts or anvils of the indicating type gages, one of which is manually retractable, have thread forms of the proper pitch and type generated on them.

Checking Major and Minor Diameters

The major diameter of screws can be checked with caliper type gages — vernier, micrometer, or indicating in practically the same manner in which the outside diameter of a cylinder

Courtesy of Federal Products Corp
Courtesy of Bryant Chucking Grinder Co

Fig 17 (A) A portable type of indicating thread gage for checking large internal threads (B) A bench type of indicating thread gage for internal and external threads

is measured. The minor diameter measurement, however, brings up special considerations. For this purpose "chisel" shaped anvils must be used on the gage, anvils whose flanks are so cleared they will not make contact at the pitch diameter or some other diameter along the flanks of the thread tooth.

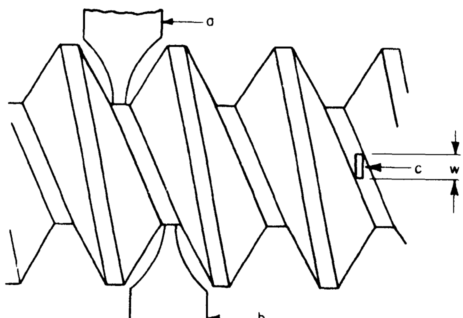


Fig 18. Schematic diagram showing how the anvils of caliper type gages should be proportioned to prevent contact with the sides of the thread.

A diagram of the gage anvil appears in exaggerated form in Fig. 18, which shows at *a* and *b* the cleared flanks of the gage's chisel shaped anvils. The two anvils also should be (theoretically at least) offset by an amount equal to one-half the pitch to accommodate the lead of the thread helix and

their width w in the other direction, as diagrammed at c, should not be so great as to touch the sides of the thread.

Checking Lead Error

The lead error in a screw thread also should be checked. For this purpose the optical comparator or the toolmakers' microscope is used. If the measurement must be made to very close tolerances (as in the case of checking the lead of a plug gage), a measuring machine (see Fig. 4, Chapter 11), is necessary apparatus. At the inspection bench, gage blocks and special points can be combined as indicated in Fig. 19 or the type of gage appearing in Fig. 20 can be secured. Care must be used in the latter two methods illustrated, not to tip or twist either the gage or the workpiece or in other words make sure that the axis of each measuring point is on a true diameter of the screw.

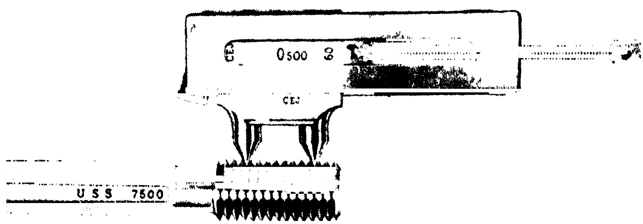
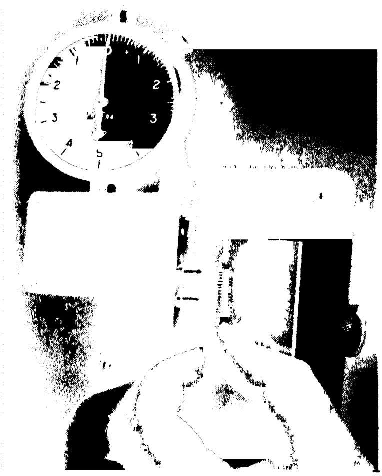


Fig. 19. Checking the lead of a thread gage by using a combination of gage blocks and special points.

There is no ready or satisfactory instrumentation available for checking the lead error for internal threads unless the hole size is large enough so that some method similar to that used for external threads can be devised. Where it is necessary to analyze internal thread conditions the plaster of Paris cast method is satisfactory.

A common manufacturing-plant mixup occurs when screw threads or nuts are measured for conformance and accepted, then plated or galvanized and finally used for assembly. The unplated screws are approved as being to size, but they will not assemble after plating. The answer is obvious, of course; the plating has built up on the screw flanks and changed the pitch diameter (also the major and minor diameters, though the increase in pitch diameter is the more troublesome ordi-

narily). The question arises, what allowance should be made, in threading screws or tapping holes on parts which are to be subsequently plated? The answer, of course, must come from the shop itself and from some knowledge of how thick a plate or galvanize coating is put on the threaded parts on the average. A series of checks can be made (perhaps by the 3-wire method or with an indicating gage like that shown in Fig. 8 on screws and on casts of tapped holes) on unplated compo-



Courtesy of Federal Products Corp.

Fig. 20. Checking the lead of a thread gage with an indicating type of gage.

nents and on the same components after they have gone through the normal plating process until a good average answer is reached. One bothersome feature, however, is the fact that plating (especially cadmium) does not necessarily go on evenly or it may flake off and clog the threads of conventional ring and plug gages. Hence, in many plants, an empirical and arbitrary allowance of 0.0005 inch for plating is established and all dies, taps, thread rings and plugs to be used on unplated pieces are bought .0005 inch under the standard screw specification and .0005 inch over the standard nut specification.*

* The Unified and American Screw Threads Standard Class 1A and 2A External Thread Limits provide allowances in the maximum dimensions which accommodate plated finishes or coatings.

Practically everything written in this section applies also to the inspection of 29 degree Acme threads, British Whitworth 55 degree threads, metric threads, buttress and square threads except, of course, that certain mathematical constants are different. Conventional plug, ring, setting, basic and master gages can be secured for these types of threads as well as indicating and special design gages.

Checking Visual Defects

Last, but far from least, in connection with screw thread inspection, is the matter of visual defects. Unless the screw is large and the pitch coarse, the visual examination should be made under a four- to ten-power magnifying glass. Such an examination may show metal slivers, thin helical strips of metal partially removed by the die and left attached in the roots, along the flanks, and on the peaks of the teeth. Rough, flaky surface finish may be seen, where the metal has knurled and chattered into tiny humps along the flanks of the teeth. These conditions, especially in the fine thread series and Class 3A and 3B Limits, can well prevent otherwise dimensionally correct screw threads from assembling.

If the die or tool is dull, the roots will be filled; or if the die itself has been improperly made, the peaks of the screw thread will come out too sharp as shown in solid outline, Fig. 21-A.

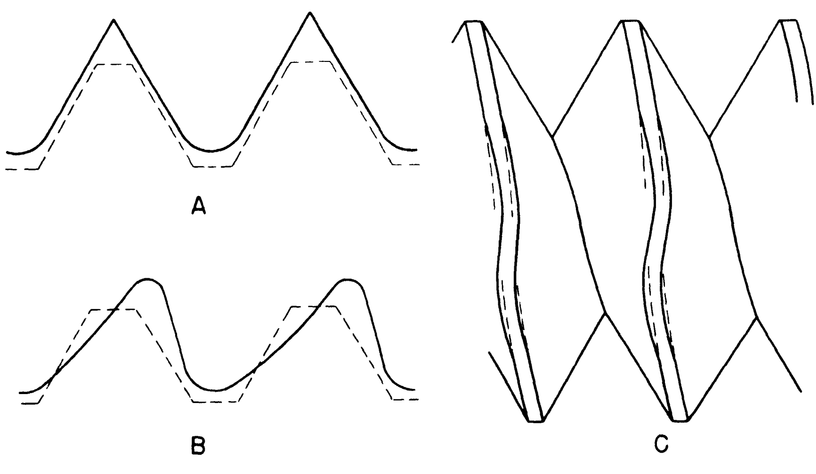


Fig. 21. Visual defects in a screw thread: (A) Sharp thread crests due to improperly made threading die; (B) The result of forcing the threading die too rapidly over the rod from which the screw is cut; (C) Drunken helix produced because of intermittent end thrust in the threading machine.

Where the machine has "crowded" the die — forced it too rapidly over the rod from which the screw is being cut — all sorts of weird shapes may result as shown by the solid outline in Fig. 21-B. The thread angle, lead error, sharp peaks and filled roots may not be apparent enough under the ordinary glass and usually the optical projector is relied on for such analyses.

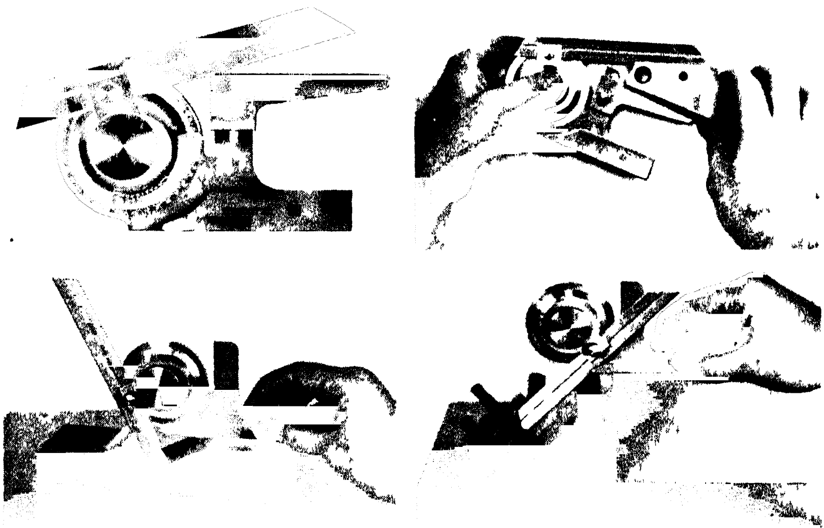
While the shadowgraph will disclose deformed threads, it cannot bring out undue surface roughness and seldom uncovers that other culprit commonly known as a drunken helix. The machine and die used to cut a thread may produce dimensionally correct thread form, surface, lead, pitch diameter, outside diameter and minor diameter, but because of a short cycle of end thrust in the machine, a wavy, jittery effect known as a drunken helix is produced on a small portion of the thread much as illustrated in Fig. 21-C, the dotted lines indicating the true helix.

If a tapped hole is deep or under 1 inch in diameter, it is impossible to detect directly the sort of visual defects mentioned above. The usual procedure is to reject a tapped hole or nut simply because a plug gage will not enter it. If it is necessary to find out why certain tapped holes are continuously rejected by a plug gage, especially when the taps themselves have been carefully checked, it is necessary to take plaster casts of the hole for more complete observation and analysis. Many times a tapped hole can be readily sectioned or a nut cut in half, thus exposing the threads for visual observation.

CHAPTER 13

Special Measuring and Inspection Problems

In addition to measuring thickness, depth, length, height, outside diameter, inside diameter, radii, and such conditions as taper, ovality, squareness or eccentricity, the inspector is called on to check angular relationships. Many times the angle between one surface and another is not too important from the point of view of precision; on other occasions it must conform to specifications with an accuracy of minutes or fractions of a degree, a relationship nearly comparable to tenths of thousandths in linear measurements.



Courtesy of Brown & Sharpe Mfg Co

Fig. 1. Commercial bevel vernier protractor and several examples of its use.

Several general methods are used to measure an angle. One is the equivalent of laying a template against the work, much after the fashion of using a radius gage or a curvature plate. The try square is a device of this type, a template literally, for checking a 90-degree angle. Corresponding to the try square, but for measuring angles other than 90 degrees, there is the adjustable instrument called a bevel protractor.

Angle, slope and taper measurements are also secured optically, with rather exacting precision, through the cross hairs and transparent protractor of a toolmakers' microscope or on the shadow screen of an optical comparator, which have been previously described.

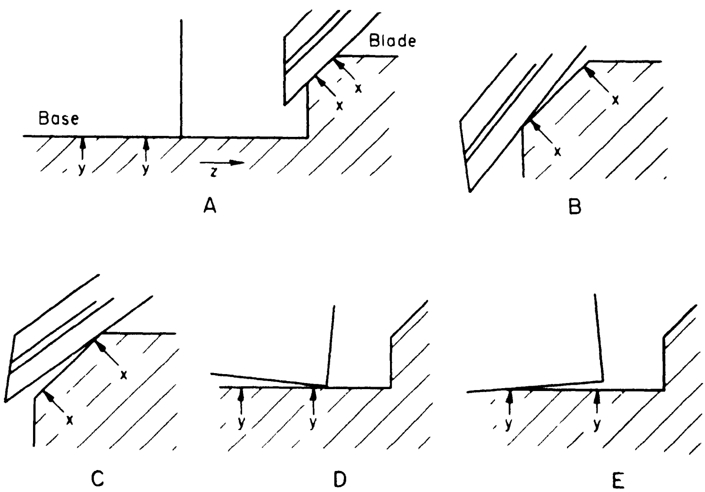


Fig. 2. In using a vernier protractor, contact between the blade and the work-piece should be as shown at (A) not as shown at (B, C, D, and E).

For superior accuracy, angles are determined by means of precision gage blocks, cylinders and sine bars as will be seen in sections farther on. Special mechanical indicating or air gages or electric comparators can be designed, constructed or contrived for precision checking of angular relationships.

Bevel Protractors

Figure 1 shows a commercial bevel vernier protractor and several examples of its use.

In using a vernier protractor make sure it is bearing correctly against the workpiece as illustrated in Fig. 2-A. It is

easy to clamp a protractor against a workpiece and have the blade tip away as Fig. 2-B indicates or for the blade to ride up on the slope as sketch C in Fig. 2 shows. Similarly, the base of the protractor can be tipped or canted as shown in Figs. 2-D and -E. The protractor must feel solid against work; at the time the angle measurement is made the protractor must not be capable of rocking. Many protractors are equipped with fine adjustment knobs which enable the inspector to revolve the blade readily to a "homing" position through the last fraction of a degree.

If, with the bevel protractor, the principle of reference and measuring surfaces is recalled, there is unlikely to be an error. First, be sure the gage's base, as illustrated at A in Fig. 2, is solidly against the workpiece reference surface at two points as at y and y. Hold the base firmly in this position and turn the blade until it contacts evenly, as points x and x of Fig. 2-A suggest, but be sure the pressure used on the blade does not exceed the pressure used on the base. Guard against inadvertently sliding the whole instrument in the direction of, say, arrow z in Fig. 2-A.

Having set the blade in proper position in relation to the base — having correctly used the protractor as a template — tighten the clamping knob, check the feel of the protractor once more against the work, and then read its scale and vernier.

Reading the Bevel Protractor

Reference to Figs. 1 and 3 will show that the circular clamp of the vernier protractor is divided into 90-degree quadrants and that it is also equipped with a vernier. The 0 of the main scale divides it in either direction; likewise the 0 of the vernier scale allows readings up to 60 minutes (1/60 degree is 1 minute) in either direction.

In reading the protractor scale and vernier it is necessary to note the direction of revolution the *vernier* 0 is taking in relation to the scale 0. If it is travelling to the right of the scale 0, as in Fig. 3, read the vernier scale, 0-60, on *that* side of the vernier 0 for its coincident line. If the vernier 0 moves away to the left of the scale 0, read the vernier scale to the left of its 0. In Fig. 3, for instance, the vernier 0 checks 17 degrees on the main scale in the upper illustration, while in the lower picture the vernier 0-line lies beyond 12 degrees on

the main scale. Reading along the vernier in the same direction, to the right, the 50-minute vernier graduation is coincident with a main scale division. Hence, the reading in the lower illustration is 12 degrees, 50 minutes.

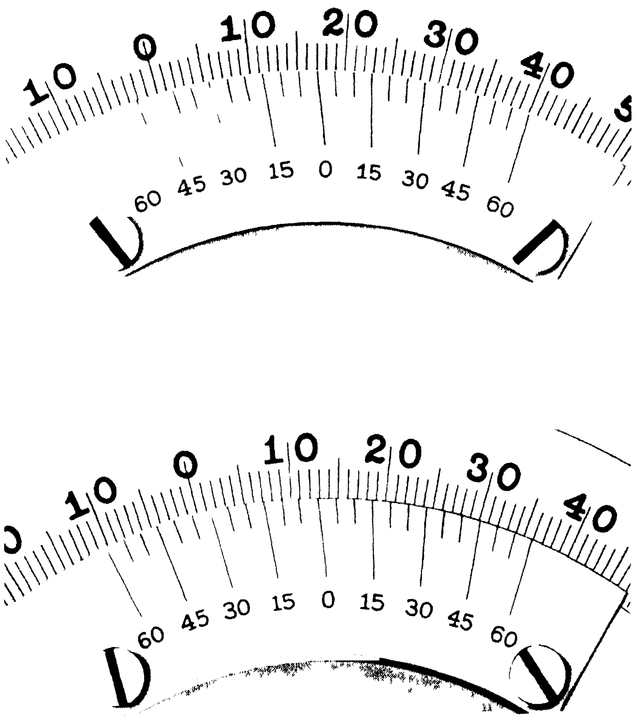


Fig. 3. (Upper) Close-up view of bevel protractor vernier scale. Protractor is set at 17 degrees. (Lower) Protractor set to 12 degrees 50 minutes.

Care must be exercised in using the vernier protractor not to register the complementary angle, 90 degrees *minus* the angle you really mean to read. Such a mistake is especially easy where the workpiece angle is close to 45 degrees. If the actual angle were 43 degrees, for example, it is easy to get reversed and register 47 degrees (90 degrees minus 43 degrees = 47 degrees).

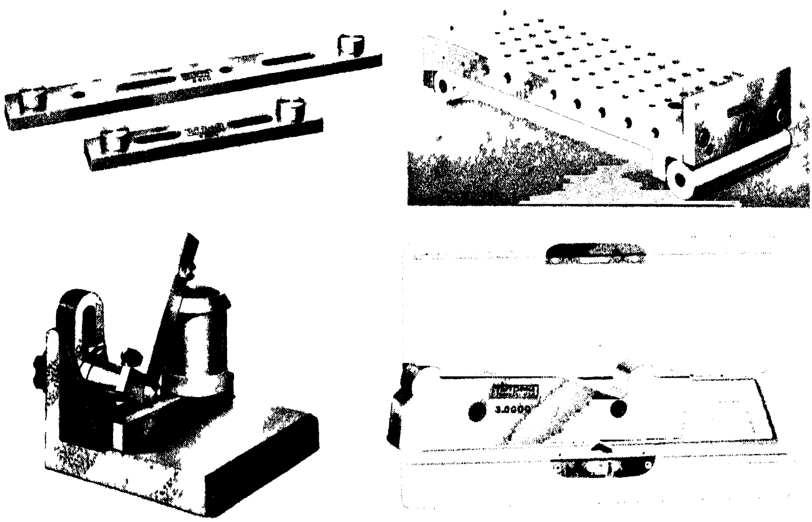
Care of the Bevel Protractor

As for maintenance, the bevel protractor should be kept rust-free and clean. Reasonable care should be exerted to prevent its being nicked. More than reasonable care should be observed to see that the blade does not become bent. When the tongue and clamp screw arrangement wears so that the blade cannot be adequately tightened, the instrument should be returned to the manufacturer for repair or renewal. It is wise to check the vernier reading on a known angle (on a sine bar, for instance) and, by means of the vernier plate screws, adjust its accuracy.

The bevel protractor has an ordinary accuracy, discrimination and precision to 5 minutes or 1/12th of a degree. This discrimination and the ability of the inspector to manipulate the gage correctly compare with the precision of the steel rule, which measures to .015 inch. When greater accuracy in measuring angles or tapers is required, the inspector must resort to more precise equipment such as the sine bar.

Sine Bars

A sine bar is a carefully machined tool steel bar which is used with two properly spaced cylinders that may or may not be fastened to it. In its simplest form, see Fig. 4, the oblong



Courtesy of Taft Peirce Mfg Co

Fig. 4. Various types and sizes of sine bars.

steel bar is 4-square, the cylinders are round and free from taper to close tolerances. In particular, the axes of the cylinders are parallel to the adjacent sides of the sine bar and are located at a definite distance apart, usually 10 inches. The bar comes with holes and slots through it so that workpieces can be more readily clamped or bolted to it. As Fig. 4 shows, sine bars come in other and special shapes, widths and thicknesses, also with clamping, revolving and base attachments.

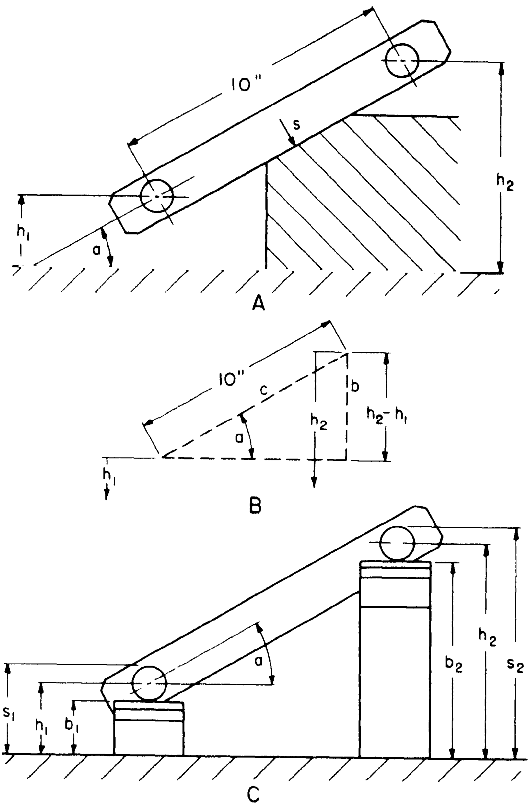


Fig. 5. Use of the sine bar is based upon simple trigonometric relationships.

Principle of the Sine Bar

The principle of the sine bar can be understood from an examination of Fig. 5. In this illustration, the sine bar is tilted and rested on the slopes of the workpiece whose angular position, the angle a, is required. If measurements h_1 and h_2

are determined, the value of leg b of the right triangle (Fig. 5-B) can be calculated since it is equal to $h_2 - h_1$. The hypotenuse of the triangle is 10 inches because the sine bar is made that way. And by trigonometry, the sine of the angle a equals $\frac{h_2 - h_1}{10}$. In other words, after h_2 and h_1 are measured, the the sine of the angle becomes 1/10th of the difference between them. (Some sine bars are made with the cylinders 5 inches apart; a few are made with cylinders spaced 20 inches. For these, the sine of the angle becomes 1/5th of $h_2 - h_1$ or 1/20th of $h_2 - h_1$, respectively.) To determine what the angle a is in degrees, minutes and seconds the value of $\frac{h_2 - h_1}{10}$ is found in a table of sines opposite the corresponding angle.

Dimensions h_1 and h_2 are ordinarily secured by a vernier height gage or, where extra precision is required, by stacks of gage blocks. Figure 5-C illustrates this diagrammatically. The centers of the cylinders or sine bar plugs do not have to be located, since the diameters of the two plugs are carefully made to be alike. Hence $h_2 - h_1$ or $b_2 - b_1$ or $s_2 - s_1$ are equal.

Suppose the gage block stack b_2, Fig. 5-C is 7.2657 inches and b_1 is 2.625 inches, the difference between the two $(b_2 - b_1)$ is 4.6407 inches. One-tenth of 4.6407 or $\frac{b_2 - b_1}{10}$ is .46407. The sine tables show .46407 as 27 degrees, 39 minutes, which is angle a.

A more expert way of handling a sine bar, perhaps, is illustrated in Fig. 6. By one contrivance or another the tapered piece is clamped or held firmly to the length of a sine bar (in the case shown in Fig. 6 this is accomplished with the aid of a standard surface plate magnetic block) and the sine bar is tilted at an angle by means of unequal gage block stacks until the upper surface of the tapered piece seems level. A height gage indicator is run along this upper surface and the height of one gage block stack is altered until there is no change of reading on the traversing indicator dial. Then the angle of taper of the workpiece is equal to the angle between the sine bar and the surface plate and can be calculated from the h_1, h_2 relationship of the gage block stacks supporting the sine bar.

A sine bar, it goes without saying, should receive the care and maintenance properly accorded gage blocks. Dirt, grease, grit, sweat, scratches, nicks and corrosion are enemies of sine

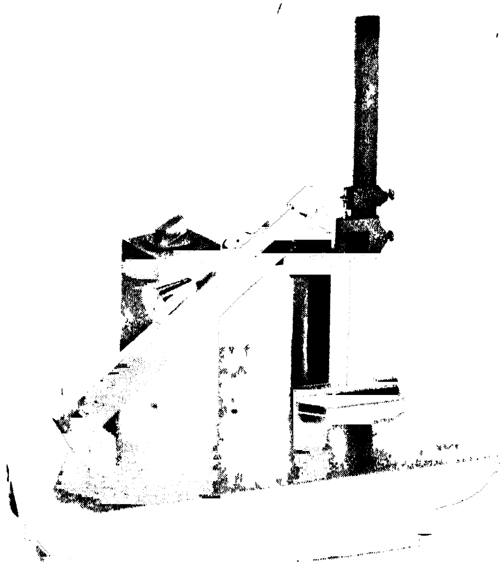


Fig. 6. One method of using a sine bar to determine the included angle of a work-piece.

bar accuracy and a sine bar should be inspected regularly for such defects.

Measuring Angle of an External Taper

The angle of taper of a tapered piece can also be measured and calculated as indicated in Fig. 7-A. The tapered piece is set up on a surface plate or machinist's flat. Two measuring rolls or cylinders, c_1 and c_2, are secured. (For this purpose the standard cylinders are usually about 2 inches long and about ½ inch in diameter. Within gage makers' tolerances they are free from taper and out-of-round and they are usually equal in size, with surface roughness generally not worse than 5 microinches.)

Equal-height, gage-block stacks are assembled for h_1 and h_1'. These heights can be almost any arbitrary and convenient choice though they are usually selected as being about one-quarter the total length of the workpiece. The rolls rest on top of the stacks, as Fig. 7-A indicates, tangent to the sides or walls of the tapered workpiece. Measurement m_1 is secured with micrometers, vernier calipers or with an indicating gage, depending on the discrimination and precision desired.

The gage block stacks are then extended to height h_2 and h_2' which, if possible, should be in the order of two or three times h_1. The rolls are again used and measurement m_2 is made.

Subtracting the h_1 and m_1 measurements from the h_2 and m_2 readings, respectively, gives in effect a triangle — see B in Fig. 7. In that triangle, the tangent of the angle a' is $\frac{m_2 - m_1}{2\,(h_2 - h_1)}$ and angle a', as sketch B indicates, is equal to angle a, which is the angle of slope of the tapered workpiece.

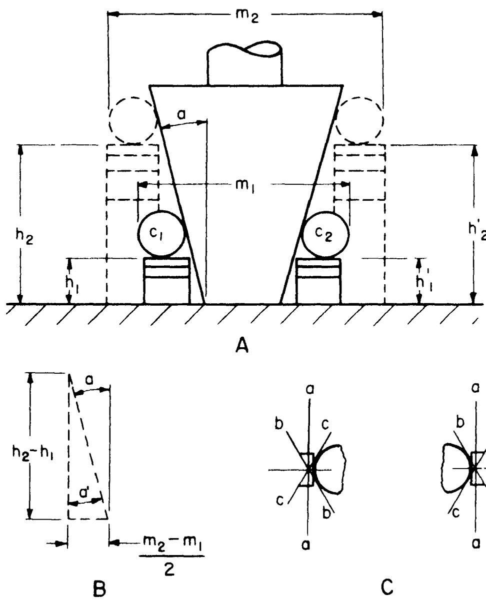


Fig. 7. Schematic diagram of the set-up and the dimensions required to determine the angle of taper of a work-piece by the measuring roll method.

In the measuring technique connected with the above, the jaws of the measuring instrument must be centered through the measuring rolls on the maximum, the true, diameter of the workpiece if it has a circular cross section. The measuring rolls must not swing under measuring pressure to the sort of position lines *b-b* in sketch C of Fig. 7 or lines *c-c* suggest in contrast to the true-diameter position indicated by lines *a-a*. Likewise, the measuring instrument surfaces must bear on the true horizontal center lines of the measuring rolls

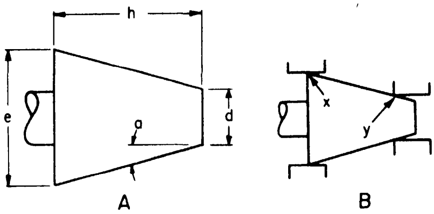


Fig. 8. A satisfactory check of a tapered work-piece should show close correlation between the angle *a*, the length *h*, and the diameters *d* and *e* shown in (A). It is impossible to measure, accurately, diameters like *d* and *e* directly as indicated in (B).

themselves. If contact is accidentally made below the center lines the rolls may lift up off the gage block stacks and give a false instrument reading.

Other Measurements on External-tapered Part

A tapered workpiece like that shown in Fig. 7 must be measured in other respects if the conformance of the piece to specifications is to be adequately checked. Determining the taper or the angle *a* is only one part of the inspection, since there must be complete correlation between angle *a*, the length *h*, and the diameters *d* and *e* shown in Fig. 8-A.

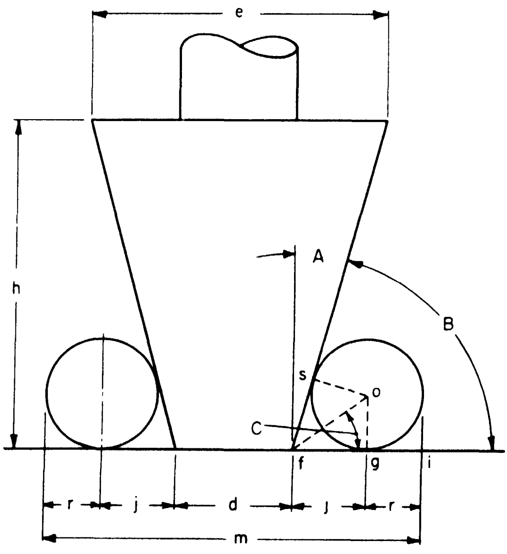


Fig. 9. Once angle *A* has been determined, diameters *d* and *e* can be calculated using dimensions *m*, *h* and *r*.

Technically, it is impossible to measure accurately diameters like e and d directly as indicated in sketch B of Fig. 8. (Workers often accept such direct measurements as these, but machined intersections — "feather edges" — like x and y are too unreliable to allow accurate direct measurement.) Therefore, the measuring rolls (c_1 and c_2 of Fig. 7) are used again as follows.

The tapered workpiece is mounted truly vertical on a surface plate as shown in Fig. 9. The rolls are placed against the workpiece as shown and measurement m is taken. Before finding diameters d and e, other dimensions must be known. Some of these can be measured directly, others must be calculated. The dimensions obtained by direct measurement are m, h, and r, r being one-half of the diameter of the measuring roll. Angle A can be determined in the same manner as was angle a in Fig. 7; angle B is equal to $90^\circ\text{-}A$ and angle C from the geometry of the figure is $\frac{B}{2}$.

Dimension j is therefore equal to $r \times \cot C$

Diameter d can now be found:

$$d = m - 2r - 2j$$

Diameter e can also be found:

$$e = d + (2h \times \tan A)$$

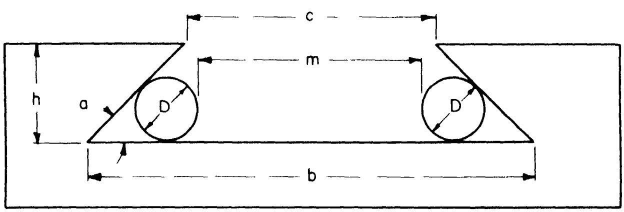


Fig. 10. Measuring-roll set-up used to check an internal dovetail.

Checking Dovetails

Another problem in inspection involving angles and tapers is the checking of dovetails. The cross section of a female dovetail is shown in Fig. 10. If, in the length of a dovetail track, the angle a, height h, width b or width c vary too widely, the corresponding male or sliding member will bind or wedge in it. So again, the familiar measuring rolls or cylinders are

used. In this case, the measurement m is an inside or width measurement. Ordinarily, in the case of dovetail checking, the angle a is determined with a bevel vernier protractor and not with the gage block, cylinder technique suggested in Fig. 7.

Knowing angle a, Fig. 10, dimension b can be determined by using the following formula:

$$b = m + D\left(1 + \cot\frac{a}{2}\right)$$

Where D is the known diameter of either of the equal-size measuring cylinders. Dimension c is then equal to:

$$b - (2 \times h \times \cot a)$$

Similarly, the dimensions for a male dovetail, Fig. 11, are obtained by measurement m, the diameters of the cylinders, D, angle a, and the following formula:

$$b = m - D\left(1 + \cot\frac{a}{2}\right) + \left(2h \cot\frac{a}{2}\right)$$

While the use of standard measuring rolls or cylinders has been described above, occasionally an experienced inspector prefers to use precision balls. Geometrically the application is

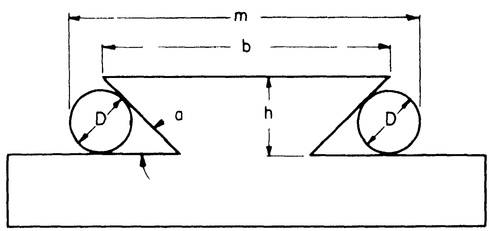


Fig. 11. Measuring-roll set-up used to check an external dovetail.

the same and there are measuring situations where the use of balls is less awkward or more accurate than the use of rolls.

In a shop manufacturing many pieces daily of a dovetail shape, specially designed indicating gages may be employed. The retractable anvils of such gages have measuring rolls permanently fastened to them. The gage is mastered to a correct size dovetail (a workpiece perhaps carefully checked by the slower, detailed method described above) and from then on conformance of the regular production dovetails can be quickly checked directly by the gage.

Measuring Internal Tapers

A practical method of determining internal tapers also involves the use of balls.

Fig. 12-A shows a tapered hole of known or measurable dimension *h*. It is required to measure angle *a* and diameters *s* and *t*. Two balls are selected; a small ball of diameter *d* such that it falls nearly to the bottom of the tapered hole as shown in Fig. 12-B, and a larger ball of diameter *D* which nearly comes up to the top of the hole as shown.

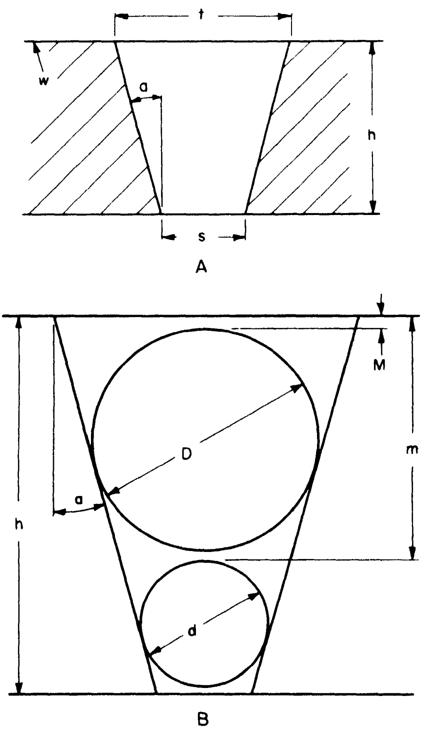


Fig. 12. A set-up involving the use of balls to determine internal tapers.

Measurements *M* and m are secured by setting up a depth gage arrangement with surface *w* as the reference surface or, if *w* for some reason is not a suitable surface for reference (it may be too small to support a depth gage), the workpiece may be set on a surface plate, the surface of which then becomes the reference surface.

Angle a can now be calculated using the formula:

$$\text{cosec } a = \frac{2(m - M)}{D - d} - 1$$

Fig. 13 shows the set-up used to determine diameters s and t. The small ball which appears in Fig. 12-B is not shown in Fig. 13 since it is not used. Dimensions M, D, h, and angle a are known, therefore we proceed as follows to find t.

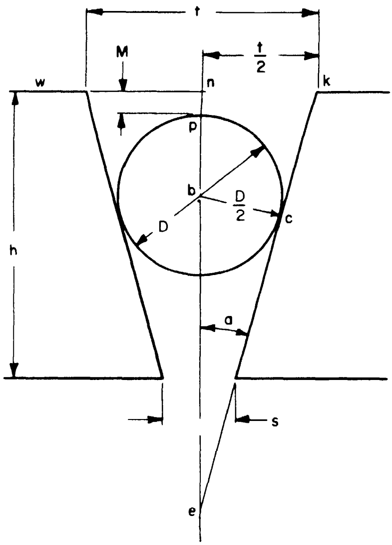


Fig. 13. Set-up with single ball used to determine diameters s and t of the taper shown in Fig. 12-A.

In triangle $e\ n\ k$, $\frac{t}{2} = ne \tan a$. Length ne is made up of three other lengths, $M + \frac{D}{2} + be$; M has been found by measurement, $\frac{D}{2}$ is known and length be which is the hypotenuse of right-angled triangle $e\ b\ c$, can be calculated:

$$be = \frac{D}{2} \text{cosec } a$$

$$\text{then } t = \left(M + \frac{D}{2} + \frac{D}{2} \csc a\right) \times 2 \tan a$$

Dimension s can then be calculated:

$$s = t - 2h \tan a$$

Special Gage Set-ups for Taper Checking

The techniques just described for measuring tapered plugs and holes not only require surface plate setups but they also take a lot of time. If there are many pieces to be checked — if, as is so often the case, the pieces are from daily production runs perhaps in the thousands — much faster means for inspecting and measuring them must be devised.

For pieces with outside diameter taper a special gage may be built which will work on the principle shown in Fig. 14-A. The indicators are mastered on a piece having the correct taper, probably a hardened taper plug measured and checked

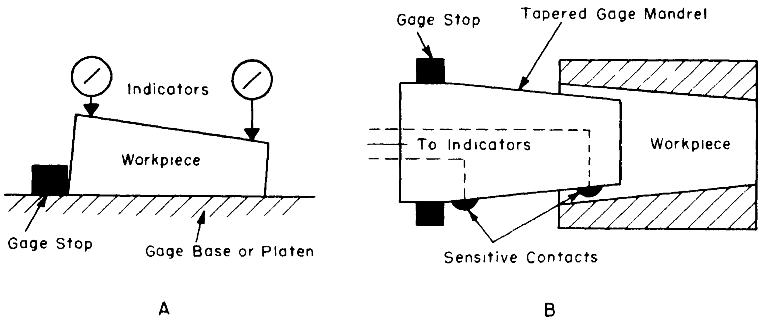


Fig. 14. (A) External taper measuring set-up in which two dial indicators are used. (B) Internal taper measuring set-up which utilizes two dial indicators.

with gage blocks and rolls as described in preceding sections. Thereafter, workpieces can be run into the indicating gage about as fast as the inspector can handle them. If either indicator, or both, varies from the "master" readings beyond tolerances, the piece is rejected.

Somewhat similarly, inside diameter tapers are checked in quantity by having an indicating gage made with a mandrel or matrix which is the duplicate of the prescribed internal taper as sketched in Fig. 14-B. The two sensitive contacts recede into sockets in the tapered gage mandrel and in so doing operate two indicators through special internal gage mechanisms. This gage is also mastered first, of course. Rather than a mechanical indicating gage and mandrel, the tapered gage plug may be an air gage plug with air jets substituted for sensitive contacts which in turn are connected to an air gage column or indicator.

Inspection of Gears

To more or less complete the discussion of the field of measurement, instrumentation and gaging, at least brief mention should be made here of the special sort of techniques required for assuring conformance of gear teeth and gears. On the whole, gear and gear-tooth checking are in a highly specialized field. The inspector who works in a shop manufacturing, purchasing, assembling or using gears in its products should make a special study of the subject, for it is much too complicated for this text to handle in its entirety. Theoretical and practical information can be secured from library technical sections in the form of books, and the manufacturers of gear cutting machinery and equipment can supply inspection, gaging and checking information. In a few paragraphs here, an attempt will be made only to furnish a guidepost to gear inspection with the description of a few of the simpler techniques.

As on the screw thread, most measurement relationships on a gear hinge about the pitch diameter. (For the sake of brevity here it is assumed the inspector has studied on his own the elements and theory of gears and gear tooth forms.) The outside diameter and the root diameter are important as well as tooth form, and tooth thickness at the pitch line. Likewise the number of teeth and their even spacing around the gear periphery must be taken account of.

Checking Conformance of Gear Hub or Hole

Consistent with other inspection routines, it is a good thing to establish an order of events in connection with the examination of gears. Perhaps the first inspection step, one commonly overlooked, would be to check the conformance of the gear hub or the hole in the gear. Many times this inspection is made at the place of manufacture of the gear blanks before the operation of generating the gear teeth, but it should not be overlooked in considering the finished product. Is the hub or hole of the gear oval, tapered, barrel or hour-glass shape? Is the axis of the hub or hole parallel to the gear axis or, more specifically, perpendicular to the face or plane of the gear disc? Is the diameter of the hole or hub within tolerances? Finally, if the gear's hub is to run in bearings or if the gear is to turn on a shaft, is the surface finish satisfactory?

The effect of some of the difficulties described above on meshing gears is to produce what is sometimes called wobble.

In theory, the line of contact across the teeth of mating gears is supposed to be parallel with the axis as illustrated at A in Fig. 15, the side view of the contact line being illustrated at B. If either or both of the gears wobble or weave as they revolve, if the hole or hub of one of the gears is not perpendicular to the disc plane for instance, then the line of contact will be tilted as exaggerated in sketch *C* of Fig. 15. Just a little of

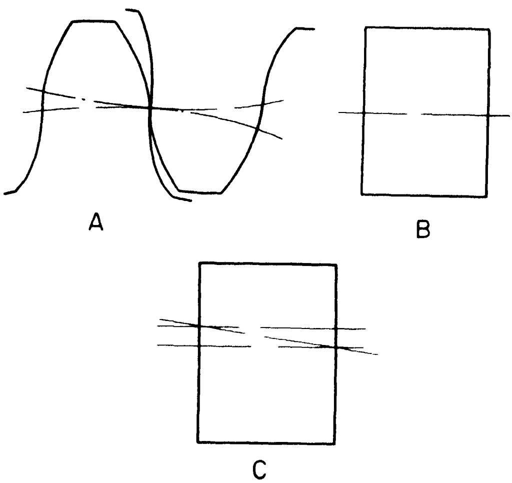


Fig. 15. (A) A pair of mating gears for which the line of contact across the teeth of the gears is properly parallel with the axis. (B) Side view of line of contact described in (A). (C) Side view showing improper line of contact resulting if either or both of the gears wobble or weave as they revolve.

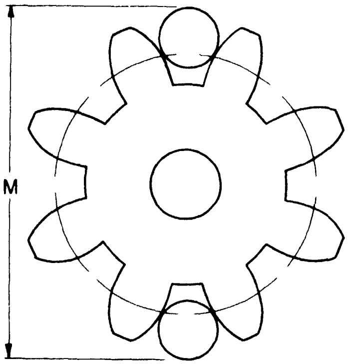
this effect will produce noisy gear trains and cause unnecessary tooth wear. It is possible that the wobble could be so bad that the interlocking gear teeth could bind or lock. Always remember the purpose of toothed gearing is to transmit motion and power smoothly at highest efficiency and, ordinarily, with as little noise as possible.

The gear hub or hole must be concentric with the pitch circle. When it fails to be, the condition commonly known as run-out exists. Then gears clack, rattle, run noisily and wear out sooner. The outside diameter of the gear should also be concentric with the center axis. If not, noise and wear result because of unbalance and unequal centrifugal forces tugging at it, conditions that become increasingly important at high speed.

Checking the Pitch Diameter or Tooth Thickness

Having examined the gear hub or hole and having located its deficiencies, the next step should be to check the pitch diameter. One way of doing this is similar to the three-wire method of screw thread measurement except that two measuring rolls or wires are used after the fashion shown in Fig. 16. The wires are located in diametrically opposite tooth spaces, if the gear has an *even* number of teeth, and as nearly opposite tooth spaces as possible, if the gear has an *odd* number of teeth.

For this purpose, a preferred wire or pin diameter for an external spur gear is equal to $1.728 - P$, and for an internal spur gear to $1.44 - P$ where P equals the diametral pitch of the gear to be measured. The correct measurement of M over wires for an external gear or between wires for an internal



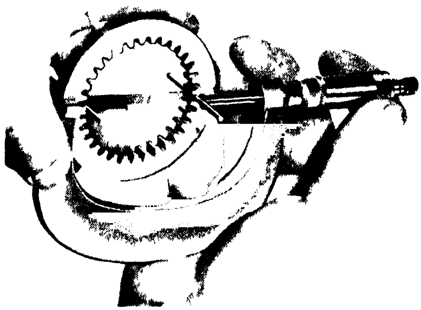


Fig 16 (Left) Set-up used when the pitch diameter or tooth thickness of a gear is to be checked with measuring rolls or wires. Fig. 17. (Right) When wires are used in measuring an internal gear, they may be held in place by a metal support strip as shown.

gear of a given number of teeth and pressure angle can be found in convenient handbook tables. Figure 16 shows measurement M, as taken over two wires located in the tooth spaces of an external gear.

In Fig. 17 the wires are held in place in the internal gear tooth spaces by a metal support strip. They extend beyond the ends of the tooth spaces so that instead of having to take the measurement between wires, a more convenient measurement over wires can be made. Before comparing the measured value taken in this way with that given in a table for mea-

surements *between* wires, however, twice the diameter of the measuring wire must be subtracted from the observed measurement.

Figure 18 shows one wire in place for a check on a helical gear. The other wire is placed in the opposite tooth space and the measurement M is taken over both wires as in the case of a spur gear.

Although measurement over wires is commonly referred to as a check on gear pitch diameter, it might be more properly designated as a check on tooth thickness at the pitch diameter. If the teeth of an external gear are too thick, the wires or pins will ride higher in the tooth spaces and measurement M

Fig. 18. Position assumed by a measuring roll when it is used to check a helical gear.

will be too great. If the teeth of an external gear are too thin, measurement M will be too small. Tables showing the difference in tooth thickness for a given difference in measurement M are also given in some handbooks.

Figure 19 shows a vernier caliper designed to measure the thickness of a gear tooth at the pitch circle. The vertical scale is set so that when the caliper is supported by the top of the tooth as shown, the jaws of the caliper will contact the sides of the tooth on the pitch circle. Such a caliper does not measure the thickness along the pitch circle, but the *chordal* thickness T.

Measurement of tooth thickness also can be made on an optical comparator where the shadow of the gear, if the gear is small enough, can be projected on a suitably accurate outline of the theoretically correct tooth form and pitch diameter. Such a comparator is also an excellent means for checking on tooth spacing and tooth profile.

Checking for Ovality and Eccentricity

Where a gear has a suitable hub, it can be mounted in a V block and a check of the concentricity of the pitch circle with the axis of the hub can be secured, using one wire and an

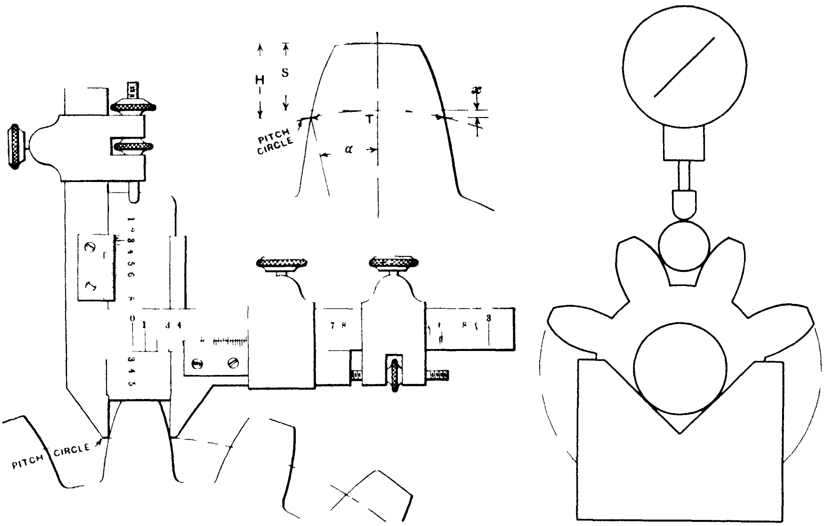
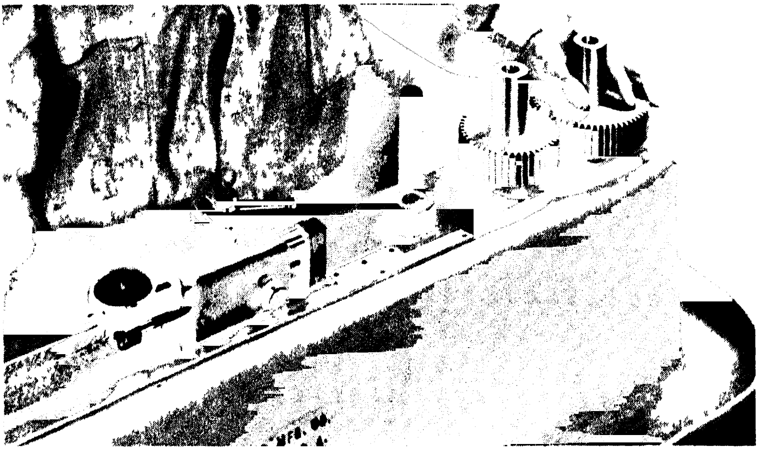


Fig. 19. (Left) Vernier caliper designed to measure the chordal thickness of a gear tooth at the pitch circle. Fig. 20. (Right) Set-up used in checking the concentricity of the pitch circle and the axis of the hub.

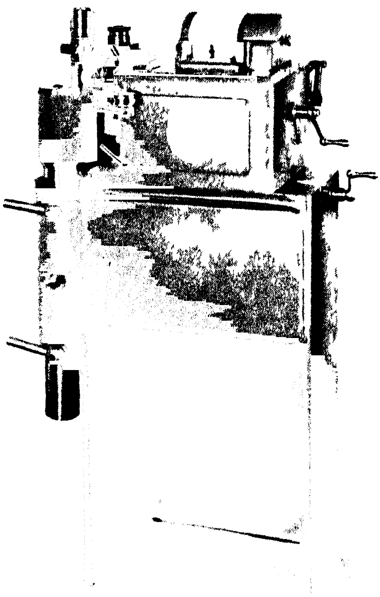
indicator as shown in Fig. 20. If the gear has a hole through its hub, the hole can be "plugged" and the plug used as a hub in the V block. This latter method may be used when the hub is unsuitable for mounting in a V block.

The outside diameter should be checked for ovality or eccentricity, especially where the gear is to enter high speed service, because either of these errors produce centrifugal and inertia effects which show up in noisy and worn gears. The outside diameter should be within tolerance or else there will be too little clearance, resulting in interference at the roots of the mating gear teeth.



Courtesy of Brown & Sharpe Mfg Co

Fig. 21. Gears are frequently checked by operating the gear against a master gear in the type of equipment shown.



Courtesy of Fellows Gear Shaper Co

Fig. 22. Gear checking equipment with provision for recording the composite errors.

The eccentricity and/or ovality of the pitch circle is frequently checked by operating the gear against a master gear in the type of equipment shown in Figs. 21 and 22. Such a test will also indicate wobble or side play.

In using such apparatus, be sure to place the two gears at the theoretically correct center distance. An inspection of this sort will determine composite errors but does not differentiate between eccentricity, wobble, ovality, indexing error, hub ovality, poor tooth form or excessive surface roughness.

Checking Backlash Allowance

When a gear is mounted so that it can run in natural fashion in proper mesh with a master gear, as in Figs. 21 and 22, the "backlash" allowance for the gear can be checked. This is done usually by locking the master gear and by setting an indicator point against one flank of a tooth of the gear being checked. Figure 23 shows the setup with the amount of back-

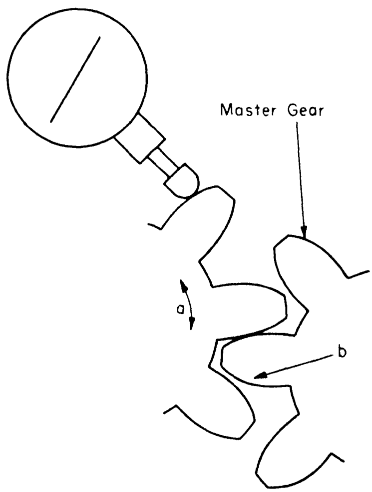


Fig. 23. Checking the amount of blacklash allowance at a given center distance.

lash appearing at *b* in exaggerated form. If the gear is rotated back and forth as arrow *a* indicates, the indicator will register the amount of backlash.

While the short discussion of gear inspection in the paragraphs above has been confined to spur gears, the same general geometrical principles apply, of course, to checking the

elements of bevel, helical, herringbone, spiral and worm gears. But here, the physical shapes of the teeth and gears naturally present special problems of measurement as compared to ordinary, simpler spur gears. It is necessary to return to the suggestion made earlier in this section where the inspector is referred for further study, instruction and coaching to special treatises on gearing and to the manufacturers of gear cutting equipment or to other gear specialists.

Visual inspection of gear components should not be neglected of course. A gear is no different than any other machine-cut product so far as the effect of surface roughness, burrs, slivers, nicks, dents, blow holes and corrosion are concerned.

Surface Finish Measurement

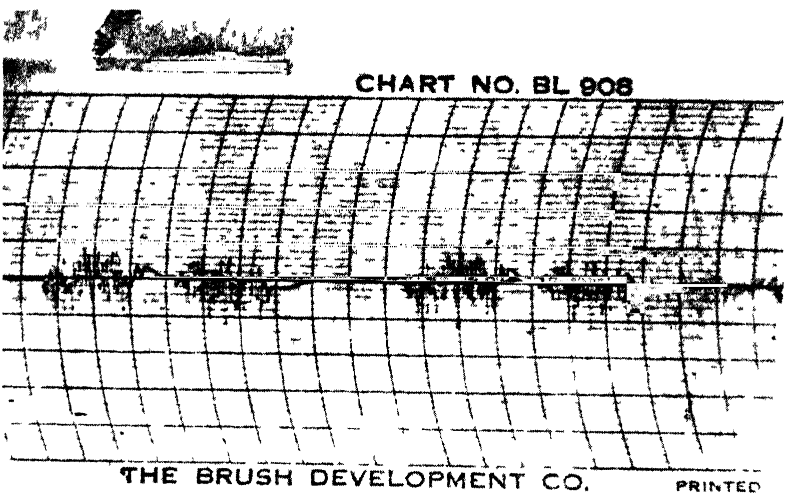
A little attention has been given already in Chapter 4 to measuring or comparing surface roughness by means of sample workpieces selected as standards or by means of replica blocks. There are, however, many circumstances where the eye or the fingernail is nowhere near accurate enough to establish the conformance of surface finish to specifications. Since the analysis of surface roughness has been reduced to terms of micro-inches, surface measuring apparatus of the general type and form of that illustrated in Fig. 24 is

Courtesy of The Brush Development Co

Fig. 24. One type of apparatus used in measuring surface finish.

coming into more common use. In principle there is a fine pointed, diamond tipped stylus for tracing the surface irregularities. The stylus, or an extension arm, is moved back and forth in uniform strokes across the workpiece surface (a limited area or path on it) by means of a motor driven mechanism. This assembly, as shown by Fig. 24, is mounted in adjustable fashion on a stand. Usually the measuring instrument and the work are supported on a solid, flat smooth surface like a surface plate.

The relatively minute vertical motion of the stylus point, as it moves over hill and dale, is transmitted by means of an electric crystal and electronic amplifier to a recorder pen and chart.



Courtesy of The Brush Development Co

Fig. 25. Record of the surface condition of a worn gear obtained with the apparatus shown in Fig. 24.

Figure 25 shows a chart obtained from checking the surface conditions of worm gear flanks. Each heavy longitudinal line on the chart represents 10 microinches, each fine line 2 microinches, and the curved lines cover increments of time or chart speed rate.

While the proper technique for operating a surface recorder is better obtained from manufacturers' catalogues and instruction books, a couple of pointers can be offered here. Remember

you are trying to take measurements in millionths of an inch. You should use the same care you would naturally exercise if you were trying, for instance, to measure a diameter to millionths of an inch with a comparator. The workpiece surface should be truly free from dirt, lint, grit, chips or grease. The workpiece should be clamped or held securely enough so that the pressure and movement of the stylus will not deflect or move it. The instrument's measuring arm, motor unit, V-block, and surface plate must be clean, smooth and flat, for the workpiece must not tip, rock or vibrate under the delicate impact of the stylus.

CHAPTER 14

Gage Checking and Calibration

Some inspectors run into the relatively special problem of checking gages and measuring instruments, which calls for observing several basic precautions no matter what type or form of gage or apparatus is being checked.

In the first place, to do a real job, the operation should be unhurried. Someone once remarked that the atmosphere in a gage lab should correspond to that in a library. An attempt should be made to do the work itself in a location — on a bench — where there is as nearly as possible complete freedom from vibration, noise, loud talk, drafts and glaring light. Try to do a job of gage checking at a time when you are unlikely to be interrupted. A gage checker should lead a cloistered life when actually at his work.

Highly Accurate Equipment is Needed

The next general observation is that the equipment and apparatus used to check shop gages should have accuracies and discriminations greater than the gages to be tested. A vernier depth gage, for example, should not be checked with an indicating depth gage whose dial divisions read no closer than .001 inch. No, check the vernier with a dial indicator whose dial reads to .0005 inch, .00025 inch or .0001 inch.

Closely allied to the above is the suggestion that the master equipment used for gage checking should not be used for any other purpose. A set of gage blocks used continuously out in the shop, for instance, should be avoided for gage checking in favor of a conscientiously maintained, seldom but carefully used "inspection set" assigned to that purpose only. Take time to keep them clean, shining, rust vetoed, unscratched, and free from nicks and dents.

If you use gage blocks, anvils, platens, V-blocks, flats, knees

and similar apparatus for gage checking be sure the relevant surfaces are truly flat. If you use cylinders, rolls or wires be sure they are truly round and not oval, that they have no taper. In general, surface roughness on checking equipment probably should never exceed 5 microinches and if you can get the apparatus lapped and polished to fractions of microinches, so much the better. Be sure such blocks, cylinders, rings and the like are suitably hardened.

There should be a regular schedule for sending basic equipment such as gage blocks, optical flats and master rings to the manufacturers for recalibration, refinishing or replacing. Depending on the frequency of equipment use, this should be done perhaps quarterly, perhaps twice a year, certainly once a year.

Gage checking should be done in an area where the temperature can stay in equilibrium for long periods of time. Get it away from doors or windows that are frequently opened and closed. Don't do gage checking in direct sunlight through windows, or near radiators, registers, steam pipes or heating apparatus. (A recording thermometer is handy apparatus in a gage checking area.) It is a good thing to get into the habit of using gloves, wooden or plastic tongs or felt pads when handling gages to be checked, or the checking equipment, so as to minimize the effect of heat transfer from the hands. It takes time frequently to set up the gages to be checked along with the rolls, rings and gage blocks to be used. When the setup is complete, rehearse the gage checking operations once. Then let the gage and checking apparatus lay idle for, say, twenty minutes to equalize all temperatures. Finally make the check or calibration as rapidly as possible with a minimum of handling.

If electric or electronic comparators and measuring apparatus are used, try to have some means of regularly checking the shop line voltage; in the same manner have a pressure gage on the air line if air gages are used as checking apparatus.

Establish a Definite Checking Procedure

Once more, a definite order of events should be adopted. The first step to be taken with the gage to be checked is to clean it thoroughly. Eliminate the variable of dirt. Secondly, try the gage, its anvils, its accessories, its clamping devices and all such for tightness. Test for end shake in a micrometer for

example. Anything loose or wobbly, any part that will move or deflect when it shouldn't, is taboo on gages. Third, a visual inspection. Clean off any rust or corrosion. Examine carefully for nicks, pits, scratches, burrs and the like. Consider, for instance, loose carbide or diamond surfaces on indicator contact and anvil surfaces. Hunt for cracks and weak spots in gage frames and bases. (Don't forget how measuring apparatus gets dropped onto concrete floors out in the shop, an event that seldom receives publicity.)

Where the type of equipment or gage demands, test next for flatness, with an optical flat, or for parallelism, taper or ovality.

If a contact point is supposed to be spherical, project its enlarged shadow onto an optical projector screen and look for worn or flat areas. Check the surface finish, perhaps. In other words, narrow down one-by-one all the kinds of variables and errors which cause measuring apparatus to go wrong until you get to the actual setting or to the actual calibration of indexing, graduations, vernier adjustment and the like. Before you reach the final step, there may be an amount of repairing, refinishing, replating, relapping or replacing. You may decide to ship the equipment or tool back to the original manufacturer.

The gage checker uses his geometry instinctively. He locates on the true diameter of a roll or ring and not on the chord; he is careful not to tip, cramp or cant a gage, the checking blocks or cylinder; the conceptions of parallel, perpendicular or flat are clear to him. He makes certain of never springing or deflecting the equipment he is testing by the use of excess gaging pressure yet he realizes that a wringing contact is necessary in particular instances.

Of course, for extra finesse in gage checking many shops have built dust- and vibration-free, temperature-controlled rooms (constant temperature rooms held within one degree of 68 degrees F.) and require that the gages to be checked shall have lodged in the 68-degree temperature room at least twenty-four hours before they are checked.

Effects of Temperature

Last but certainly not least in this brief treatment of measurement and gaging some consideration should be given to the effect of temperature changes both in the workpieces

being gaged and in the metal make-up of the gaging apparatus. For the most part the gaging of a workpiece is a matter of linear measurement and the length or linear dimension of any metal piece changes with the temperature. An inch length of the average ferrous material will alter by about .000006 inch (6 millionths) with each degree change of its temperature. A similar figure for aluminum is .000013 inch (13 millionths) and for copper and copper alloys about .000009 inch (9 millionths).

To get a practical picture of how a steel piece, for instance, can expand without your realizing it under average temperature increase conditions, suppose you pick up a bar 10 inches long which has been at the ordinary room temperature of,

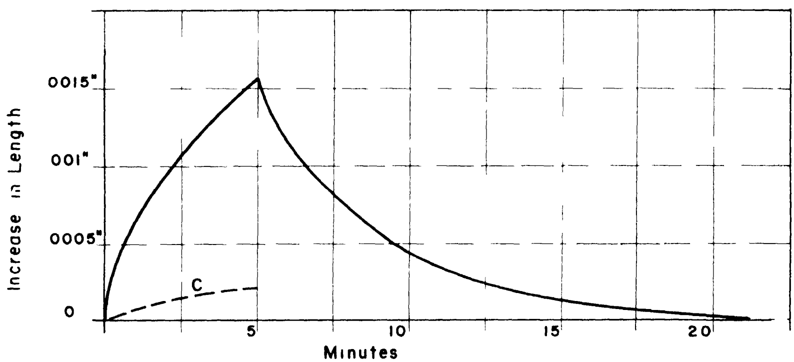


Fig. 1. Chart showing gage expansion due to handling. Solid curve: 24 inch caliper held in hands for 5 minutes and then set down to cool. Broken line: temperature rise for same caliper when handled with ¼-inch thick felt pads.

say, 70 degrees and hold it in your hand for 10 minutes. Generally speaking, by that time the temperature of the bar will have gone up some 10 degrees and it will be .0006 inch longer:

$$10 \times 10 \times .000006 = .0006$$

In short, the normal handling of a ten-inch steel bar under average factory conditions can increase its length a half-thousandth inch without any one realizing it.

Furthermore, while a piece of stock or a measuring instrument will heat up rapidly, it takes it a long time to cool down to its previous (room) temperature. The chart in Fig. 1 shows what happened to a 24-inch caliper held in two hands for 5

minutes and then set down to cool off. (The dotted line, *c*, shows the temperature rise where the same caliper was handled with 1/4 inch thick felt pads insulating the hands.)

Where modern assemblies are requiring tolerances and fits to .0001 inch (all of which makes for a smoother quieter running and much longer lived automobile power plant or refrigerator unit, for example), not only must surface roughness under 10 microinches be achieved but also attention must be paid to the effects of temperature on sizing and on measuring the conformance of metal pieces to the size required. Hence, the modern technology of turning, boring, milling, grinding, lapping and honing with refrigerated and temperature controlled coolants. The inspector must enter the game by realizing what errors his hands can produce not only by incorrect manipulation of his gage but also by changing the accuracy of his gages through the effect of handling temperatures.

To be practical about it, it is unusual or unlikely for a sufficiently noticeable error to creep into the average measurement if the instruments and workpieces are handled as much as possible with the fingertips and if the measurement is completed within a minute or so. But to stand enveloping the frame of a portable gage in your fist while you talk with the new girl from the timekeeper's office for ten minutes and then turn to make a precision measurement is another story.

As a standard temperature for measurement, 68 degrees F. has been selected in the United States as the temperature at which any linear measurement will be considered correct. If the work is measured at a lower temperature it will be, of course, smaller and vice versa. Again to be practical, the actual room temperature seldom has too much effect (even though it might be 90 degrees) because it is possible for workpiece, gage and master all to be at the same temperature.

The Need for Gage Control

It's a pretty safe gamble that eight out of ten micrometers owned and used by machine shop operators are "off" by some .0005-inch either in zero setting, end play, calibration or with anvils worn out of parallel. Disc and ring masters which are used to zero comparators and dial bore gages become forgotten, neglected, and seriously worn. Maybe the psychologists can explain why a worker will set his dial bore gage to a rusted

ring master he unearthed almost anywhere and proceed fatuously and complacently confident of his ability to ream exact one-inch holes because the legend stamped on the ring says 1.000-inch. The finer the tolerances the more serious such a complex becomes.

Lately also, the discovery is being made in many factories that gage elements wear away much faster than has been the common belief. Traditionally, a gage wear allowance up to 10 per cent of the tolerance has been permitted — which was all right where the tolerances were plus or minus .010-inch or even plus or minus .005-inch. But when manufacturing tolerances narrow to tenths or less, a broad wear allowance goes out the window.

Under some conditions it does take a gage a long while to show error-producing wear. In others, the gage surfaces might wear back several thousandths in a single day. That's where the rub comes in; too often nobody knows how fast the gages do wear. Hence, gage control.

There is no set formula for the rate of gage wear. A man may check brass pieces steadily for a week and have his micrometer show no appreciable wear. The next day he may be measuring sand castings and have a tenth or so chewed off his mike anvils in a matter of hours. Heavy-handing a thread ring gage onto just a few oversize threads may spoil its accurate setting. The best formula is to know the time elapsed and the number of gagings on what type of material and parts during the intervals between which the gage is checked for wear.

No type of gage seems to be immune to wear, whether it has flat or spherical contacts, whether it is an indicating comparator platen, a ring or tapered plug, or whatever. Gages with roller anvils usually require less maintenance. Heavy versus light gaging pressure has less effect than might be suspected. Other parts of gages should not be forgotten; check the skirts of air plugs, and calibrate indicators and gage meters because internal gear teeth, pivots and jewels also wear.

The material a gage contact is made of is important. Anything softer than tool steel hardened to 50-60 Rockwell C seems useless. Chrome plate on hardened surfaces has withstood from 10 to 100 times as many gagings, without appreciable wear, as plain hardened steel, while tungsten carbide

anvils have been known to stay in shape through 100,000 gagings. Despite such performance records, however, never quite trust a gage unless it has been checked or unless a valid wear record is available. But inspectors and workers can't always be stopping to check a measuring instrument; hence again, the desirability of gage control.

It used to be that no factory bought any measuring instruments. As part of his trade, the mechanic, machinist and inspector furnished his own micrometers, verniers and test indicators. He made whatever plug and flush pin gages were needed. Whether or when they were ever checked for accuracy depended much on his pride of craftsmanship. A trace of this old system still clings even in many modern plants where the individual often buys and uses his own, rather than company-supplied, one-inch micrometers.

An in-between system still flourishes in a great many factories where the worker owns some of the instruments he uses but the plant supplies the remainder, which make up the majority. Often too, the factory-bought instruments — indicators, height gages, fixed gages, gage blocks, et al — are put right out on the floor with no more record of them from then on perhaps than the annual inventory. How or when they were checked was secondary. In many plants gage control still embraces some of these traditional "hang-overs."

However, during the last decade definite company policies have been developed concerning the type, design, application, selection, procurement, maintenance and complete control of any and all gages, measuring instruments, size control equipment and testing apparatus. The ideal setup is perhaps yet to be reached but progressive organizations are working toward it. The new approach means systems for issuing, maintaining and returning gages plus up-to-date records of every move.

There are about as many kinds of gage control systems and records as there are establishments or individuals using them, all much alike and differing mostly in details. The situation resembles buying men's suits — outwardly each garment seems to be the duplicate of the other but any suit selected from the rack must be tailored, or altered at least a little, to properly fit the buyer. It would be impossible to outline here a universal gage control plan that would precisely meet the requirements of all manufacturing areas; the system for any one plant or

department requires study and trial. However, there are certain fundamentals which can be touched upon.

Planning for Gage Control Raises Questions

An adequate gage control system should be able to answer two fundamental questions correctly:

1. Where is the gage right now?
2. How accurate is it?

There are other basic questions, for instance, plant management wants to know how much money is tied up in measuring equipment. But just getting the answers to 1 and 2 raises further detailed questions. To whom, where and when was the gage issued? What was its condition then? When was it last checked? How long has it been on the job? On what product, part or material is it being used? How often per hour or per day? Is it due to be returned? Is it missing?

As questions like these are being answered, the type, scope and extent of a record system is being patterned. And then other decisions have to be made. Who will make and keep the records? Where? Will gages be kept in some sort of central storage and issued as required or will "gage control" simply maintain some patrol system of constant surveillance out on the factory floor? Or a mixture of both? Who will check the gages and who will be responsible for gage control? Some answers come from examining existing systems.

Gage Control Programs in Use

In certain large manufacturing companies Gage Control is a responsibility of the Inspection and Quality function. It is a separate department under that heading with its own supervisor. Physically it operates the gage lab, a records office, a central gage crib and the disbursement of gages through tool cribs or similar facilities strategically located in manufacturing areas. In addition to gage maintenance, Gage Control is charged with the analyzing of size control and the measuring requirements of Production and with the designing, selection and procurement of the measuring equipment which is needed. Gage Control specifies the gages to be used for each operation and job. These duties are carried out with help from Produc-

tion, Methods and Tool Engineering. Management holds Gage Control responsible for the inventory of measuring and testing equipment and for meeting company accounting requirements of budgeting, depreciation and obsolescence.

In a number of smaller plants, also, the custom has grown of placing the gage selection and maintenance responsibility with the chief inspector. Such a setup usually functions under much more restricted and improvised conditions from the standpoint of gage control facilities than does the large plant organization.

Traditionally gages and measuring instruments have been classed to a considerable extent as small tools along with jigs and fixtures, reamers, milling cutters and the like. Hence gage control has been a routine of the tool crib in many establishments. Usually under such circumstances Manufacturing and Tool Engineering specified the type and extent of gaging and its equipment for production with Inspection selecting many of its own requirements.

One occasionally found variation requires all gages to be requisitioned from a tool and gage crib and returned there either after immediate use, at shift's end or surely by week's end. The crib does not toss the gages back on the shelves but sends them to Inspection for checking, correction and repair, whereupon they are returned to the crib. In other words, the crib's source of supply for gages which it is allowed to issue is the inspection department.

At the far end of the spectrum is the factory where Manufacturing, Engineering and Inspection each procure and provide whatever gaging and testing equipment each thinks it needs, an arrangement usually accompanied, as already intimated, by little or no organized attempt to check, maintain or replace measuring devices.

Every so often, especially in the smaller establishment, some one inspector may take on to himself an unofficial, individual responsibility for gage checking in the area he serves. One way or another he will secure or gain access to equipment — a set of gage blocks, a comparator, a sensitive dial bore gage perhaps — and find time to examine not only his own instruments at regular intervals but also the micrometers, gages and equipment used by adjacent machinists.

In between the extremes of practically complete gage control

and none at all a large variety of patterns can be found in industry. The trend lately has been to pay more attention to the subject and to invest more money in gages, instruments and size control equipment and also in means for maintaining and controlling them. This occurs as a plant grows in size; again where its product machining becomes more diverse and complex; and finally where competition or product requirements (missile parts are one example) demand closer tolerances.

Gage Control Records

Records are probably the essence of a gage control system. In industry they may vary from simple card files to complex ledgers and punch card systems. Most of them display common factors an enumeration of which might help the inspector in contriving or revising a plan if he were faced with the problem

Every gage, instrument or size control unit should have its own serial number. Such a series of numbers may be completely

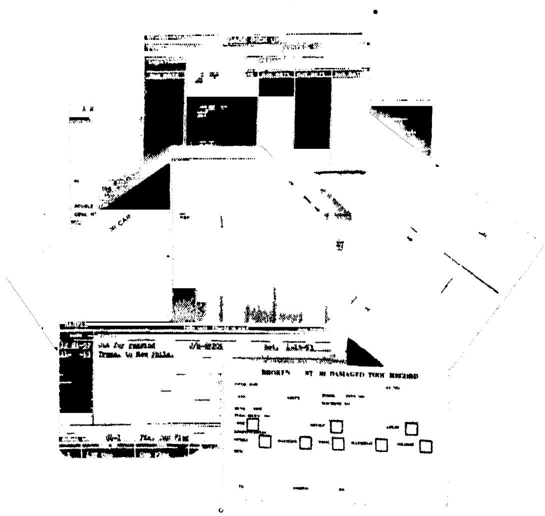


Fig. 2. Samples of the wide variety of cards, tally sheets, ledger forms and other records used in various plants as part of their gage control record systems

independent or it may be related to an existing plant register system. One rule in connection with gage serial numbers seems to establish a necessary safeguard. Once a serial number has been issued for a gage, that number is never used again. Even when a gage is replaced by a facsimile, give the latter a new number. Old gages that have been ordered out of commission and scrapped have a knack for reappearing on the job. Who fishes them out of junk piles and sneaks them back into use is one of the unsolved mysteries of gage control.

Usually a basic record includes the gage's serial number, date of purchase and from whom (or date of manufacture if made in the company tool room), its general description including make and model number, and some word concerning its purpose or use. If it is a special design, some reference is made to an engineering file, correspondence or purchase order. For inventory purposes the record usually contains the original price or cost and, often, the up-to-date depreciated value.

For each gage, a continuous record is kept of its location. A column for dates is provided paralleled by space in which to note whether it is in stock — unissued — or to whom and where it has been given out on that date. ("To whom and where" includes sending it out or away for repair.) Another column provides space for noting the date of return. The same record form often provides space for notes about the product, part or material the gage is being used on.

Another must is some form of receipt covering the issue and return of the gage. These vary from a simple brass tool check to a carbon copy slip containing sufficient legal phraseology to insure a successful suit against the gage borrower in the event of failure to return the gage. In the better programs the gage receipt contains provision for marking in most of the data required to recapitulate the sort of information described in the foregoing on the main record forms.

Maintaining a rather careful, detailed record of gage condition is customary. For example, a micrometer might be issued although it is known to have a zero setting error of minus .0002-inch and anvils out-of-parallel by two light bands (23 millionths). Upon its return another record is made of its condition to see if it has worn more. Such a record also registers who made the gage checks and when the gage was finally repaired or replaced.

It will be found that the successful gage control setup depends more on the care and conscientiousness — the dedication — of some one person in gage control who manages the records than it does on the physical makeup of forms or routines established by executive order. Good gage control means constant attention and rather rigid discipline. Whoever keeps the records is best placed to pull the right levers on time to assure that discipline.

Gage Surveillance

To maintain accurate, up-to-the-minute records is seldom enough, however. Gage Control people find it necessary to adopt supplementary methods for keeping track of gages because gages are apt to disappear, not show up on time to be checked, or be subject to other dilatory tactics of the users.

It pays to mark the serial number on gages, instruments and size control equipment rather prominently, the psychology being to deliberately call attention to them, to attach importance to them, and thus perhaps remind the user that they need to be checked frequently. Some plants use brass or plastic discs for this purpose, others paint the numbers on.

The biggest trouble is to get gages back in on schedule to be checked. This means having some idea, in the first place, of about how long a gage can safely be left on the job. In some situations gages wear fast enough to warrant calling them in at the end of every shift. Others need policing once a week, some once a month. The correct scheduling of gage examination comes from experience, and especially from closely following and analyzing the gage condition records mentioned in a foregoing paragraph.

Also to successfully recall gages for maintenance, it is usually necessary to carry a stock of duplicates. To deprive a worker of a frequently used gage for several hours, while it is being tested and repaired, meets with resistance and also involves too much costly, emergency repairs. Exchanging the worker's gage with an accurate alternate solves the problem.

Most gage control systems provide for flagging the gage record when a gage is issued, the flag serving to signal the date it should be returned. The records are combed each day with orders sent out for the return or exchange of the gages involved.

In a few factories, where gage use is regular, uniform and not too severe, a system of "color coding" has been found effective. A number of the gages are painted or striped red for instance; their duplicates are colored blue. Red gages are for use, say, during the first and third weeks of the month and the blue ones during the alternate weeks. Each week, Gage Control brings one group up-to-date. If a red gage is found in use during a "blue week" it is suspect and automatically recalled. Color coding also includes monthly control intervals for some gages — green, say, for January, March, May, etc., and yellow for February, April and June. Usually color code cards, posters or calendars are displayed in manufacturing areas advertising which gage color is legitimate or official for the particular period.

A gage control staff usually needs to do a certain amount of detective work. A percentage of workers for some reason resort to various artful dodges to avoid the gage control, recall and replacement routines. Then too, human frailty enters — some lapse in completing gage records, some neglect to return a gage that is due in. It pays, especially in larger operations, to have someone from Gage Control more or less comb the manufacturing areas from time to time, making a sort of inventory and hunting especially for culprit gages that belong back in custody for reexamination and rehabilitation.

The effort and cost of framing, installing and maintaining a practical gage control program almost inevitably pays off in an upsurge of product quality, a reduction in scrap and rework, and lowered assembly expense, because required dimensions are more regularly met. A measurement is never much better than the reliability of the instrument making it.

CHAPTER 15

Measuring in Millionths

Many inspectors today are faced with the problem of measuring size differences of 50, 20, or 10 millionths of an inch or even less. Blueprints now appear with tolerances in the millionths. Methods for machining and measuring in terms of 10 millionths of an inch are not uncommon. This chapter will attempt to focus on this relatively new extra-precise technology of millionth measurement and at the same time give the inspector a few tips on ways and means of improving and modernizing his technique and help him to develop a respect for that elusive millionth of an inch.

The Man Who Measures Millionths

The man (or the woman) who can measure to a millionth of an inch should have an "even temperament" and must have a high degree of emotional stability. He should take pride in his work and be always striving to improve his skills and his job knowledge. There are many training courses available. These are offered by professional societies and by the manufacturers of the measuring instruments which the inspector must use. They will help him to solve many of his measurement problems and improve his ability to use his gages to the best advantage. He should have a good background in basic mathematics which he can augment with technical courses in such subjects as physics, metallurgy, statistics, and mechanical engineering. There are many publications and reference books available for the millionth inspector and he should try to read as many of them as he can so as to keep himself up to date with the continuous progress being made in the millionths measurement field.

The man who measures millionths may in many ways be a perfectionist because he is working in an area which many

people regard as perfection in the art of measurement. However, if being a perfectionist is believing that one can always find exact answers to all measurement problems, we would suggest that an inspector with that philosophy will be doomed to disappointment. Millionths measurement has many limitations and unknowns — which we will explore in this chapter.

Good judgment is a quality that one expects to find in any inspector but the millionths measurement inspector should have this attribute highly developed. His judgment will be strengthened by his training and experience and by his deliberate and careful attention to his craft. He must be neat, clean and painstaking, but should restrain himself from chasing the will-o'-the-wisp of an impossible perfection. The millionth measurement inspector should be a very special person but he must, at all costs, keep a sense of humor — about himself and the nearly impossible situations he is sure to find himself involved in as he chases the elusive millionth of an inch.

Gaging Equipment

Before attempting millionths measurement, the inspector is urged to become fully acquainted with the gages and equipment available. He should evaluate the manufacturer's claims, follow instructions meticulously and, above all, check the accuracy and ability of the apparatus he plans to use.

Mechanical indicators with dial readings in "half-tenths" (0.000050 inch) have been on the market for many years. Most of them magnify spindle movement through a gear train, but some make use of a reed mechanism or a twisted wire principle.

To gain exacting results with a mechanical dial indicating gage, it should be used on a sturdy comparator over as short a range as possible. The size difference between the master standard and the work-piece probably should not exceed 0.0005 inch. In addition, the accuracy and repeatability of the indicator should have been carefully tested and the amount and location of any instrument error known. Other precautions applying to millionths measurement, discussed in detail later, also need to be observed. If the job requires the reading of size differences in increments of less than 0.000050 inch, either air or electronic equipment should be used.

Developments in air gages during the past decade not only have made them highly suitable for hole measurements but have also led to their frequent selection when size differences between

50 and 10 millionths of an inch were to be measured. Those with dial or column graduations in increments of 50 and 20 millionths are favored. Air calipers, air cartridges, test set heads, and air rings provide many shops with the solution of gaging problems in the 10- to 50-millionth tolerance range where thickness and outside diameter measurement were involved.

Magnification in air gages is attained by employing certain combinations of internal master jet diameters and plug jet diameters, and reducing the clearances between the plugs and the work-piece. Air gages have been marketed that register — theoretically, at least — size differences of 5 millionths of an inch or less. Although the inspector may apparently see size differences of a millionth or two on the scale graduations of an air gage, he should probably accept such readings with reservation. Barometric pressure, temperature, and humidity may have to be considered.

An air gage is strictly a comparator which is "set" to a master or some size standard. The validity of its measurement depends very much on the known, exact size of the master. Hence, it would not be justified to assert an internal diameter in terms of a particular and exact millionth-inch size with an air gage "set to" a commercial master ring gage which has its dimension certified only to within 10 millionths of an inch.

The exact level of the meniscus of a mercury column is difficult to determine where millionth-inch observations are required. At high magnifications the pointer of a dial type air gage, or the float in a column type, is liable to flutter enough to affect the guess about that last millionth. In the present state of the art it may be better to confine the use of air gaging to measurement within 10 to 50 millionths of an inch and turn to electronic apparatus or interferometry for detecting size differences between 1 and 10 millionths.

In the case of electric and electronic gages, the position and motion of calipering metallic contacts, spindles, jaws, or anvils are translated through variations in voltage, current, resistance, reactance, frequency, magnetism, or capacitance to meters. Magnification is accomplished through what are essentially transformers so that a millionth or so will "look" as big as, say, 1/16 inch on a meter scale.

Many commercial models of this type gage provide switching mechanisms so that different magnifications and ranges can be selected. A gage might, for example, provide a plus or minus

0.001-inch scale for "rough" work with a value of 0.0001 inch for each of its twenty dial divisions. It could then be switched to a ten times greater magnification, with each dial division registering a 0.000010-inch size change over a total range of plus or minus 0.0001 inch. A third magnification could allow a total scale range of plus or minus 0.000010 inch, with each dial division marking 1 millionth of an inch.

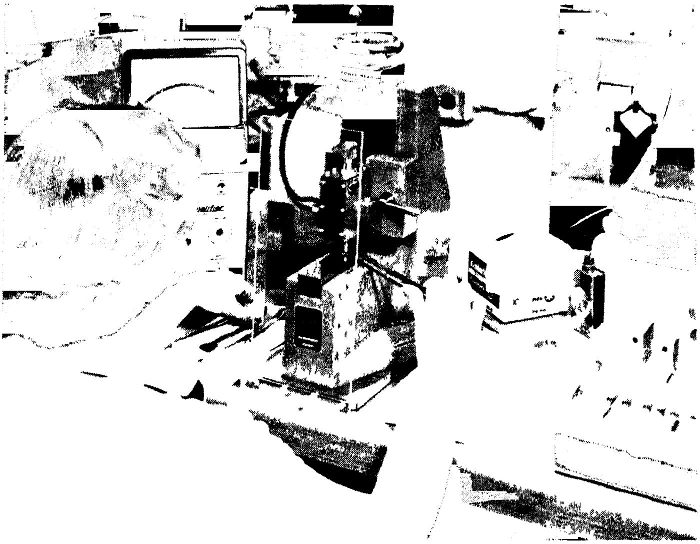
Before measuring with any make of "millionth comparator" which uses internal electric or electronic circuitry, the inspector should fully understand the manufacturer's instructions. He should have a calibration chart of its accuracy from one end of the dial to the other. Since, to some extent, these gages are sensitive to supply voltage fluctuations, a knowledge of these variations at the outlet is valuable. Too much voltage deviation may affect gage calibration. The inspector should find out from the gage supplier how and where to master the gage — whether (1) at each end of the scale with minimum and maximum masters or (2) at the zero center of the scale with one master. Both methods of setting may be required.

All types of ultraprecise gages can fail the user for some or all of the reasons previously listed. The professional standing of the inspector as well as the reliability of his measurements is in proportion to his conscientious observance of precautions against uncertain measurement.

The Effects of Environment — Temperature

The expansion and contraction of metal from temperature changes is figured in millionths. An inch of steel will lengthen about 0.000006 inch with a 1-degree F. rise. A general, similar figure for copper and brass is 0.000009 inch, and for aluminum, 0.000013 inch. The international standard inch is exactly 2.54 centimeters at exactly 68 degrees F. If an inch of steel is measured at 69 degrees F., it would be 1.000006 inch long. Obviously, in millionths measurement an error of 0.000006 inch is large.

A piece of steel held in the hand absorbs heat faster than we think. A 10-degree temperature rise in a matter of five minutes or so is not impossible. Then it may take hours, literally, for the metal to cool off and contract to the original length. The professional technique in millionths measurement is to handle gage blocks, masters, and work-pieces by remote control with insulated forceps, or tweezers, (see Fig. 1) with plastic pads or gloves.



Courtesy of Federal Products Corp

Fig. 1. While peering through a plastic shield, this inspector uses tweezers with insulated tips to place parts under the gage Previous to measurement, parts are stored on the heat sink (lower right) until they are stabilized at the controlled room temperature

In industrial situations the usual first thought is an air-conditioned, temperature-controlled room (see Fig. 2) for mil-

Courtesy of Sheffield

Fig. 2. (A) Exterior view of a typical controlled environment room. (B) Controlled environment room being used for working and measuring to millionths of an inch

lionths measurement. Such a room is valuable and handy — occasionally absolutely necessary — but there are circumstances where it may fail and others where some different and far less costly arrangement will do as well.

An air-conditioned gaging laboratory must be free from drafts. Maintaining a general 68-degree F. temperature is not enough. There have been installations where a stream of 60-degree F. air from an inlet blew directly on a sensitive gage while a dead spot over in the corner of the room stayed at 72 degrees F. Ideally, the cool air circulation should be so deflected and gently diffused that a match flame would not flicker and yet a thermometer would read 68 degrees F. anywhere in the room.

Avoid the natural tendency to place a gage near a window. Infrared rays of direct sunlight strike the gage and tend to heat it and the work, although the surrounding temperature is kept assiduously at 68 degrees F. Similarly, radiant body heat affects the work. Plexiglas barriers serve quite satisfactorily in shielding the instrument and the work from convected body heat and the inspector's "hot breath." A practical and inexpensive commercial setup for eliminating many of the effects of convected body heat is illustrated in Fig. 1. In certain situations the gage or interferometer is entirely boxed in with transparent plastic, and the operator manipulates the parts with long-handled, insulated forceps introduced through self-sealing rubber portholes.

In addition to providing a stable atmospheric environment and guarding millionths measurement from stray and erratic temperature variations, probably the most thorough method of securing temperature stabilization is "togetherness." This technique is, in fact, the essence of temperature control. In simple words, place the masters and work-pieces on the gage anvil in metallic contact with each other and leave them thus for twenty minutes at the very least, or much better, for one, two, three hours or more. Such a "soaking" procedure is especially essential where gage-blocks have been wrung together.

Often it is handy to use a "heat sink" which is usually a slab of steel or aluminum of considerable mass with a clean smooth surface placed beside the gage as in Fig. 1. Gage blocks, masters, and work-pieces are placed on the heat sink (after they are cleaned) as a convenient means of obtaining common metallic contact for equalizing their temperatures.

Can millionths measurements be reliably made in the ordinary

heat of manufacturing areas where there is neither air conditioning nor temperature control? The answer for size differences from 0 to 5 millionths is no; and from 5 to 10 millionths, probably not safely. But differences between 10 and 50 millionths can be measured with considerable assurance if a few precautions are observed.

Measurements do not necessarily have to be made at 68 degrees F. Accurate results can be secured at 98 degrees F., or any other reasonable temperature. The trick is to have masters, work-pieces, and gages all at the same temperature (and, of course, be made of the same materials or those whose expansion coefficients are alike). First, free the gage from itinerant air currents and sudden drafts. The best way probably is to almost box the gage in. Secondly, stabilize the job temperature by nestling masters and work-pieces together on the gage anvil, leaving them to interchange heat for an hour.

Before leaving the gaging setup for a period of temperature stabilization, be sure that the masters and parts and gage anvils are clean, that gage blocks are wrung, and that all other preparations for measuring are completed. This should include setting and mastering the gage and even going through the motions of a tentative measurement or two. By so doing, the final measurement can be taken adroitly and quickly.

Having a reasonably accurate thermometer nearby is always reassuring in precision measurement. A scratch-pad record of hourly temperature variations in the vicinity of the gage gives the inspector an idea of the uniformity, or otherwise, of the ambient temperature at the gage. An accurate thermometer is a must where size differences of a millionth or two are to be measured in a temperature-controlled environment.

Errors Due to Vibration

To register consistent, repetitive readings, a gage should be subjected to as little vibration as possible — ideally, none. In most manufacturing and urban areas, a constant tremor exists to which everyone is so acclimated that no notice is taken of the frequency at which the surroundings pulse and vibrate. When trying to read a precision instrument the value of stillness is realized. Under the majority of circumstances, vibration, thankfully, may not bother measurement much. However, when tremor is sufficiently intense to make a meter hand flutter, it is time to take action. Because instrument vibration is largely

indiscernible, one of the better clues to its presence is lack of repetition. When an inspector fails mysteriously to get consistent readings, particularly repeat readings, vibration can be one of the causes.

Usually the first attempt to eliminate vibration is to slip cork, felt, or rubber pads under the gage, an expedient that is effective probably more times than it is ineffective. More elaborate measures have included mounting the gage pedestal or even floor sections on tar mastic.

The solution may be as simple as moving the gage a few feet to another location. (Plant layouts often locate delicate instruments close to aisles where fork trucks travel.) Again, a rigid bracket or shelf lagged to a brick wall can provide a steady support. One plant solved the problem by placing its gages over a heavy floor beam until the maintenance foreman, also looking for solidity, installed an air compressor on the same beam line, three bays away. Distant punch presses also have a faculty for making meter hands move to their rhythm. Concrete piers brought up from the ground through the floor are good unless there is heavy truck traffic nearby.

If there is anywhere near a single solution to vibration proofing, it is gained by weight and massiveness, by something "solid" whose natural vibration frequency differs substantially from the immediate surroundings. Following this reasoning, one should try putting a gage on a surface plate resting in turn on a heavy table.

Odd as it may sound, one group succeeded in stilling the transmission of vibration to a gage by setting it on a pedestal of 16- by 20-inch chimney cinder blocks. The blocks were carefully stacked one on the other without masonry (which is part of the trick), and they were not fastened to the floor. As a safety measure the uncemented cinder-block pier was encased in a solid wood box cleated firmly to the floor. The sides of the box came as close as 1/4 inch to the cinder blocks but did not touch them.

A Constant War on Dirt

Dirt might be labeled enemy No. 1 as far as gaging is concerned. It is ever present and so much a part of our accustomed environment that it is unnoticed, forgotten, or ignored. But when the accuracy of measurements in millionths is at stake, the inspector becomes as acutely conscious of it as a surgeon.

Those skeptical of the effects of resident dirt could perform the following experiment. Leave a cleaned work-piece and millionth-inch comparator untouched for a day or overnight. Then measure the piece, taking pains not to clean it or the gage in any fashion. Next, carefully clean the piece and the gage, and take a reading. The size difference between dirty and clean will be a couple of millionths and probably more. If the inspector then gives the clean gage anvil and the work-piece the traditional final wipe-off with the palm of the hand, he will probably find the work-piece seemingly up to 10 millionths thicker.

Grubby hands have provoked many a precision measurement error. Add as other causes of error lint from clothing, wiping cloths, and bench and instrument covers. The latter should be of plastic and frequently cleaned. Paper towels and tissues are lint breeders though not as prolific as cloths. Some inspectors use clean chamois; others prefer a soft artist's brush for last-minute cleaning. Special wiping tissues, almost completely lint-free, can be purchased commercially. With oil and moisture as vehicles, resident dirt has an insidious faculty for creeping into an ultrasensitive gage to foul spindles, plungers, and pivots, and make it sluggish.

Climatic conditions require the use of rust inhibitors in most of the country. These add to the cleanliness problem because they attract dirt. The usual routine is to spray or bathe the coated surfaces with a suitable solvent — but observe one precaution: Be sure the solvent is filtered clean.

Some gage laboratories adopt the expedient of maintaining low-humidity environment through the use of electric dehumidifiers or silica and calcium-chloride dehydrators. They also observe the rule of never touching clean work-piece surfaces or gage anvils with moist fingers. Thus rusting and the need for rust inhibitors are eliminated. Incidentally, an electrostatic dust precipitator in the lab or in the air ducts assists the air filters.

Metallurgical Effects

One effect of metallurgy has been considered in the discussion of temperature co-efficients of expansion and other effects will be dealt with in subsequent sections on penetration, deflection, and wear. But there are still additional reasons why an error of several millionths may occur because the inspector failed to realize the weak points of different materials.

Work-piece surface conditions vary according to their com-

position. Hardened tool steels can be given finishes so smooth that surface roughness is not obvious. On the other hand, it is safer not to trust a smooth-appearing surface. For millionths measurement at least, try to determine the amount of surface roughness. The gage almost invariably measures the peaks. If the work-piece is to be subjected to any metallic contact, rubbing, friction, or wear, the peaks will soon disappear.

Stainless steels (and occasionally chrome plate) may look very smooth, but sometimes tiny flecks of chrome expand bubble-like or loosen up at the surface to disturb millionths measurement. Tungsten carbides present brittle-hard, smooth surfaces, but beware of nearly invisible pits. Tiny as they are, they may accept a spherical gage contact and "throw off" a millionths measurement. Aluminum surfaces oxidize, leaving a nearly impalpable, white, powdery coating of aluminum oxide with which to contend. Aluminum oxide is very hard and extremely abrasive. Although it may not directly affect accurate measurement, it has been known to swiftly lap a millionth or so off the surface of a gage anvil or contact.

In trying to distinguish size differences in terms of 1 or 2 millionths of an inch, it will sometimes be observed that the metal "grows." This is frequently true of work that has just been hardened or tempered — in other words, where it has been subjected to considerable internal stress. A piece will measure a certain number of millionths. An hour, a day, a month later, the same dimension may be several millionths greater. If the few millionths inch of size increase is important, as where tolerances are in millionths, some means must be adopted to stabilize the metal before final sizing. Sometimes it is difficult to convince the manufacturing division that a measurement discrepancy is due to an unstable, internal metallic structure.

There is a possibility in millionths measurement that the size, area, and weight of a work-piece will create an error in obtaining a true dimension. For example, in a test made by the National Bureau of Standards with a 4-inch gage-block, the length was measured (a) in a horizontal position, and then (b) while standing upright, and finally (c) while vertically suspended. The results are shown in Fig. 3. When upright, the block shrank or compressed to become 0.00000008 inch shorter, but it stretched 0.00000008 inch when suspended, as at (c). Elongation and shortening varies as the square of the length. The 0.08-millionth-inch error in measurement of a 4-inch block,

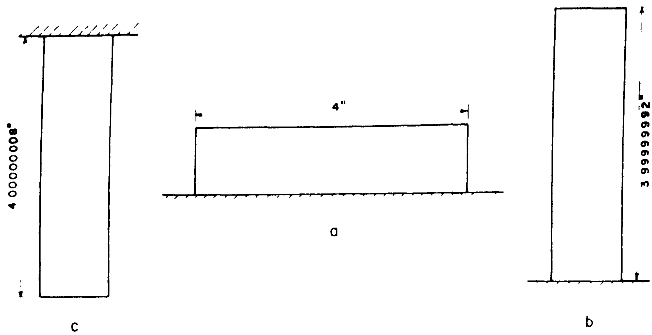


Fig. 3. Stretching and compressing of a 4-inch gage block due to its own weight. The changes in size, shown at (b) and (c), will vary with the square of the length.

or a smaller error obtained in gaging a shorter one, is negligible for all practical purposes. However, if millionth-inch tolerances and measurement are required on a part whose basic dimension is 18 inches in length, thickness, or diameter, the compression or elongation of the metal due to gravity may be pertinent.

Contact Point Penetration

At first thought, the phenomenon of penetration seems nothing more than an illusion which the inspector has never observed or considered as a source of error until he attempts measuring those last few millionths. Penetration is the bending, depressing, deforming, and yielding of the surface of the work-piece under the pressure of the gaging contact. Its effect is illustrated in greatly exaggerated fashion in Fig. 4.

A succession of tests have shown that with a diamond-tipped, spherical contact point of 0.125-inch radius pushing down on a standard, hardened steel gage block under only a 6.4-ounce pressure, the penetration amounts to 10 millionths of an inch. Even with a contact pressure of as little as 1 ounce (27 grams), the penetration amounts to about 3 millionths of an inch.

The penetration effect varies with the metals being gaged, depending mostly on Young's Modulus for the material. Penetration into tungsten carbide is often negligible because of its greater rigidity. In comparison, brass yields readily. Hence the inspector needs to be alert to penetration when he uses a carbide block as a master and then measures a brass cylinder. Probably, penetration in the surface of a cylinder is a little greater than that in a flat surface, which in turn is greater than in the bore

of a ring. The penetration error doubles when the piece part is being measured with outside or inside calipering jaws, as seen at *C* and *D* in Fig. 4.

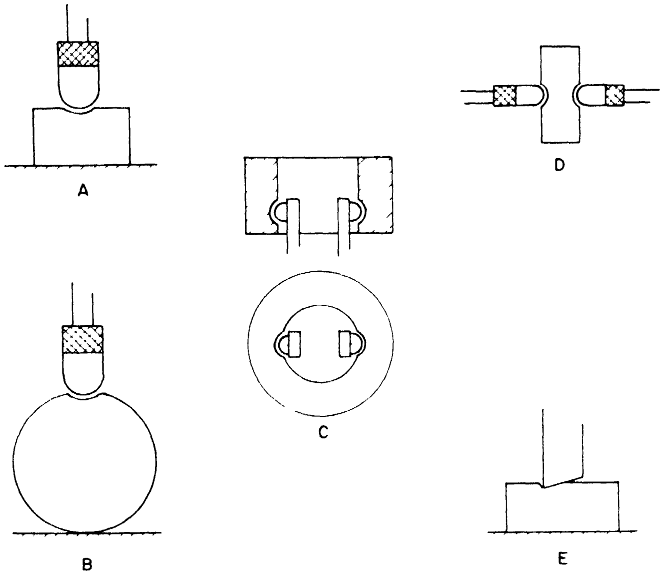


Fig. 4. Exaggerated examples of penetration, the deforming of the work-piece surface under the contacting pressure of a gaging point. It is an important factor in millionth-inch measurement.

Some might say immediately that if the spherical contact were not so hard, or diamond-tipped, the penetration would be less. Perhaps this is true, but if the spherical contact point is relatively soft, might not it flatten a trifle? Again, others might recommend a flat gage contact, since the penetration should be less (depending on the contact area). It is extremely difficult, however, to obtain perfect parallelism between the plane of a flat contact and the gage anvil. Consequently, penetration like that illustrated at *E* in Fig. 4 would most probably occur.

Another thought might be that an error from penetration could be nullified by the use of extremely light gaging pressure. The problem, however, is not solved quite so simply, as will be seen from discussions of deflection and of gaging pressure versus internal friction.

To escape penetration error from metallic gage contact pressure, some argue that an interferometer or an air gage might be used for millionths measurement. In neither case is a mechan-

ical contact pressed against the work-piece.

But the light waves of an interferometer do "penetrate" in their fashion, or act as if they do. The phenomenon, known optically as change of phase, accompanies reflection at the surface of a light-absorbing material. The change of phase for fused quartz is negligible; for a properly polished steel surface the reading error would not ordinarily exceed 0.7 millionth of an inch. The used gage-block or work-piece surface, however, can have enough lapping marks or other surface defects so that the change-of-phase error can mount up to some 3 millionths of an inch.

Air-gage proponents contend that neither optical nor mechanical penetration occurs when air is used. But for one thing, they forget or ignore the equivalent effects of the surface roughness of the work-piece or master. (A discussion of surface-roughness error, explaining how air tends to measure the "pitch diameter" of the surface ridges, is included in Chapter 10.) If air gages are to be used for the sort of extremely close work implied here, the masters and the work should have no discernible roughness. Where one micro-inch of surface roughness can be measured, expect an air gage to err by an amount close to a micro-inch from this cause.

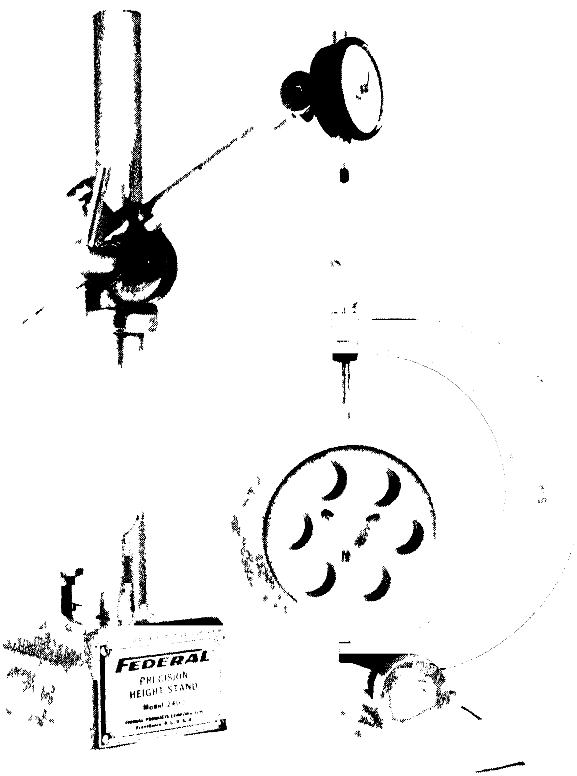
Air-gaging systems display other inherent, error-producing characteristics that are deceptive and difficult to detect and correct. As yet, some professional metrologists are unwilling to rely on air gaging for detecting size differences less than 5 millionths.

Contact Pressure Steals Millionths

Since contact pressure interferes with those last few millionths of measurement, extra sensitive gages exert pressures varying from a few grams to several ounces, depending on the design. Some makes of electronic gages permit the operator to regulate gaging pressure between an ounce and 4 ounces. Another manufacturer advertises contact pressure of 1/10 ounce (2½ grams).

For detecting size differences of less than 100 millionths (0.0001 inch), gaging pressure is seldom trusted to human touch. Contact pressure in most precision gages is controlled by spring action, as in the case of dial indicators. In a few designs, gaging pressure is exerted by weights and counterweights.

No doubt the ideal condition is to use as little pressure as possible in order to neutralize penetration deformation, and deflection; but at the same time, there cannot be any wavering of contact against the work-piece. Contact must be certain. Invariably there is some internal force opposing gaging pressure — dirt, friction in pivots and bearings, "hysteresis" in springs, or the pull of a magnetic field. Uncertainty in measurement comes when the gaging pressure is reduced to a value just about equal to any internal reaction force, and a sort of null point is reached. Vibration is also a major cause of uncertain readings with light gaging pressure. The usual symptoms for the trouble are fluttering, unstable meter readings or lack of repetition.



Courtesy of Federal Products Corp

Fig. 5. A setup which demonstrates the effect of gaging pressure on the deflection of the gage frame. The indicator shows gage deflection when the work-piece is set in place.

Deflection "Sneaks" into Measurements

The simple experiment illustrated in Fig. 5 could be enlightening to anyone incredulous about deflection. A micrometer is mounted as a snap-gage and set to the work-piece diameter with the customary finger pressure on the thimble. The spindle is then locked and the work-piece withdrawn. A 10-thousandth-inch indicator is also set up as shown in the illustration to register the vertical motion of the micrometer frame and barrel. When the work-piece is moved in and out between the locked jaws, the indicator shows the micrometer frame deflection. (This deflection and the indicator reading can be increased by screwing the micrometer spindle a little more tightly down on the work-piece.) If the work-piece is rigid enough so that its deflection can be neglected, its diameter can be obtained by adding the indicator reading to that of the micrometer.

Deflection is about the stealthiest of all the error-producing conditions. It "sneaks" into measurements, yet is hard to believe present because the unaided vision cannot discern it. Deflection errors often are mistakenly included with those of temperature, penetration, and looseness. It is ever present if there is contact gaging pressure of any amount. In some setups, merely an ounce or two of pressure can produce deflections measurable to several millionths of an inch. The basic reason why gage frame deflection interferes with correct measurement is illustrated in Fig. 6, which shows a spring-loaded contact exerting downward pressure on a work-piece with a force F.

Simultaneously, an equal and opposite reaction force R becomes set up exactly equal to F. This opposing force tends to make the gage bracket bend upward, as at D. But force R operates with a leverage or moment arm L. Such mechanical advantage not only increases the immediate deflection D but adds to the deflection of the gage upright D'. Without going into Newton's law of equal and opposite reaction, or the mathematics of moment arms, or Young's Modulus, Fig. 6 shows that reaction R, though equal to force F, will more readily "spring" the gage frame because of leverage L.

The cure for this type of deflection error is to (1) have F as small as possible; (2) make the throat depth L as short as possible; (3) make the gage frame rigid and of adequate cross section; and (4) securely tighten any gage clamps or adjusting devices. The sturdy, virtually massive gage construction seen in Fig. 7 helps reduce deflection errors to negligible quantities.

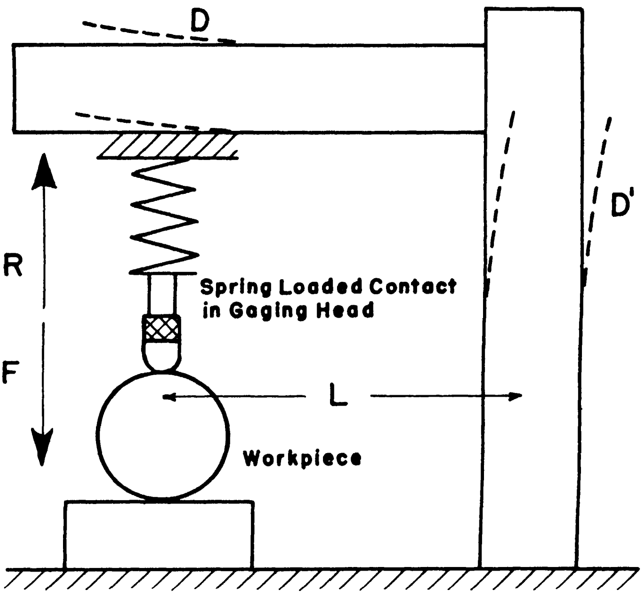


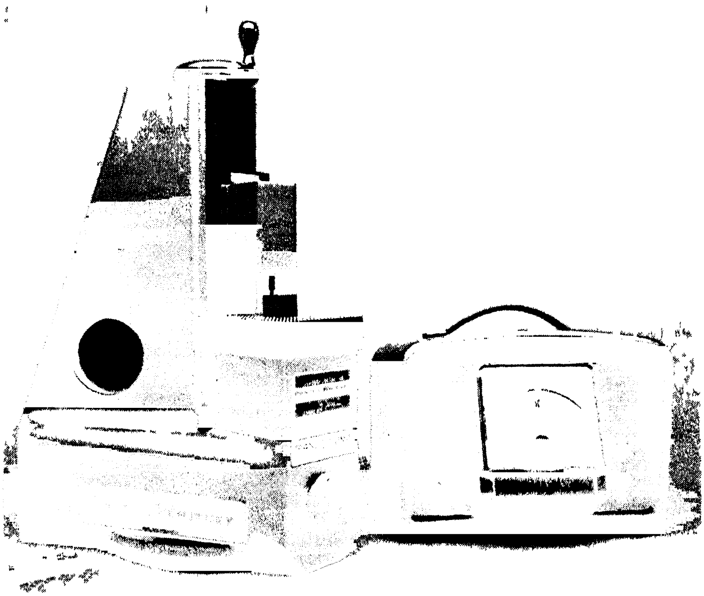
Fig. 6. Diagram showing how the mechanical advantage gained by the gage frame moment arm amplifies the deflection due to contact pressure.

The obvious protest might be offered that if the gage is used as a comparator, its deflection error (as well as penetration) is in effect nullified. The deflection of a gage set to a master should remain the same when the latter is replaced by the workpiece, a contention that proves true in many circumstances. On the other hand, deflection, when friction is present, is an unpredictable variable. If a comparator is inherently prone to this combination, inexplicable differences in readings may appear, especially in millionth-inch measurement.

Lack of repetition in results can thus point to the presence of deflection. Often deflection errors are uncovered when a piece happens to be measured in two different gages. The gage that fails to hold a zero setting for a period of time might be offering a clue to excessive deflection.

Deflection errors creep into inside-diameter calipering measurements and are especially troublesome where master rings are to be calibrated to within a few millionths of an inch. In the present state of the art, most master-ring checking is done on

"measuring machines" more or less typical of the one seen in Fig. 8. The "machine" jaws are mastered or zero-set with gage-block stack calipers as shown. Then the ring is centered over the jaws and the difference between the readings, in millionths, is read on the meter. Probably both the stationary and the sensitive jaws bend and penetrate a trifle.



Courtesy of Colt Industries, Pratt & Whitney Machine Tool Div.

Fig. 7. The main frame of this millionth-inch comparator is designed with a "built-in" web to resist deflection and prevent errors from this source.

In this type of measurement, the belief that the same amount of jaw deflection would be transferred without error during the comparison of the work-piece and the master could turn out to be erroneous. The diagrams in Fig. 9 show why. While zero-setting a gage-block caliper, the solid reference jaw R and the spring-actuated sensitive jaw S might deflect as illustrated at A. The direction of possible deflection of each jaw is indicated, though the amount is greatly exaggerated. Another deflection possibility is seen at B, where the work-piece has replaced the master. There are many such jaw-deflection combinations.

Some of the difficulty comes from the friction (F in View B, Fig. 9) between the work-piece and the gage platen. Being spring-loaded, the sensitive contact S tries to drag the work into

final gaging position. To reduce deflection produced by this effort, free-rolling cylinders or balls are sometimes used under

Courtesy of Federal Products Corp

Fig 8. An electronic internal measuring machine has been set to caliper jaws spaced with gage blocks prior to the checking of master ring gages.

the work, as suggested in View C. One make of measuring machine has a cam device which, in effect, locks the calipering jaws in gaging position while the master is replaced by the work-piece. Jaw deflection is not eliminated by this scheme (nor penetration), but the error is virtually nullified because the arrangement keeps the jaws positioned precisely alike for each measurement.

Jaws of precision calipers for internal diameter gaging are made of rigid material with cross-section areas great enough to reduce bending errors to negligible amounts. Gage designers shun any jaw length (*L*, View C) greater than 1⅝ inches in order to minimize bending leverage. When the hole size is less than 0.750 inch, however, jaw cross section must be reduced because of the lack of space in the hole. (View D, Fig. 8, illustrates how jaws overlap to fit into a small hole.) Jaw deflection becomes a fairly important problem in holes smaller than 0.250 inch.

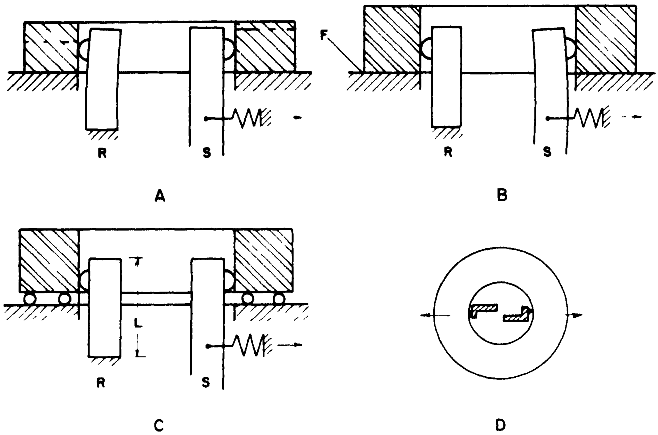


Fig. 9. Views (A) and (B) show two of the many possible ways internal gage jaws can deflect. Cylinders or balls reduce friction drag of a workpiece, View (C). View (D) shows how jaws are made to overlap for measuring small holes.

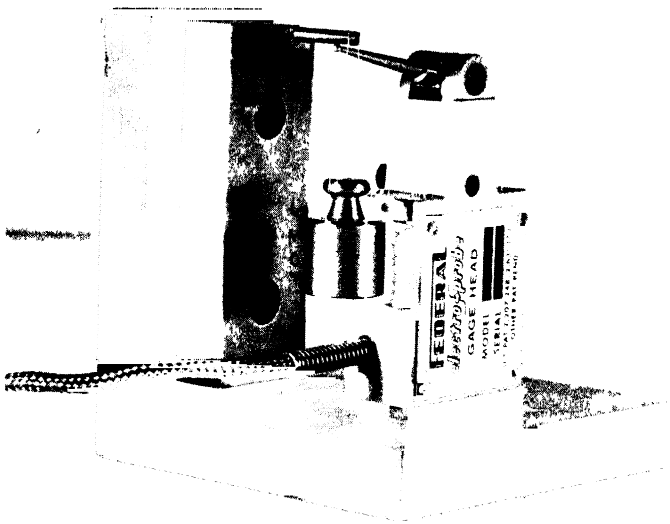
The demonstration in Fig. 10 verifies the deflection potential in jaws of small cross section. Such a jaw is shown solidly clamped on a jig, and an electronic transducer gaging point is making contact with it. The connected meter was set to read zero when no weight was hanging on the end of the jaw. But when, as in the illustration, a 20-gram weight was hung on the jaw, the electronic indicator registered a deflection of 5 millionths of an inch.

Some Sources of Looseness

A first cousin to penetration and deflection as an error breeder in millionths measurement is looseness. It displays the family trait of being hard to detect and is often unobserved. Its symptoms — meter flutter, lack of repeat readings, and inaccurate

calibration — are also characteristic of other gage troubles and thus contribute to making looseness difficult to diagnose or isolate.

Parts that make up a gaging assembly often mysteriously work loose at inopportune times. Probably a systematic check



Courtesy of Federal Products Corp.

Fig. 10. This arrangement demonstrates gage jaw deflection. The electronic gage head revealed a 5-millionth-inch movement when a 20-gram weight was hung on the securely mounted jaw.

for looseness should be made periodically. One way would be to set the gage contact on the gage anvil and zero the meter. Finger pressure or a light tap can then be applied to each location where looseness might appear, and the meter will reveal its presence. There are a number of typical places where looseness can be expected.

Be sure the gage anvil is clamped down securely to the gage frame. Seemingly rigid, it can float on a film of air or it can teeter a few millionths of an inch in its holder. If the gage post is round, remember that most cylinders are turned or ground a trifle oval and any hole or socket will be bored out of round by a similar few millionths. All too often the major axes of ovality are 90 degrees to each other and the post then readily pivots in the hole. Metal chips or plain dirt between post and

clamp can produce the same pivoting effect. Two flat, joining bracket surfaces tend to yield a trifle (no matter how hard they are tightened up) if either surface is not completely flat or a ridge of dirt has crept between them. If the gage has spring reed mechanisms, check and tighten the assembly of the springs to the gage frame and parts.

A fairly complete knowledge of the gage meter may help in a search for loose pivots, worn bushings, and plunger side play. The gage contact point should be tight in the spindle. A diamond or sapphire insert can work loose in its setting. Having checked and corrected as far as possible for sources of looseness, the inspector is wise to recalibrate the gage throughout its range, also testing for repetition at each calibration station.

Don't Ignore Wear in Gages

Perhaps because wear is the most common cause of gaging error, it is probably the most ignored; peculiarly too, because it is about the most obvious and easily checked of discrepancies. Although wear crops up in instrument pivots, bushings, and plungers, it is usually more troublesome on anvils and contacts. What occurs under typical conditions is illustrated in View A,

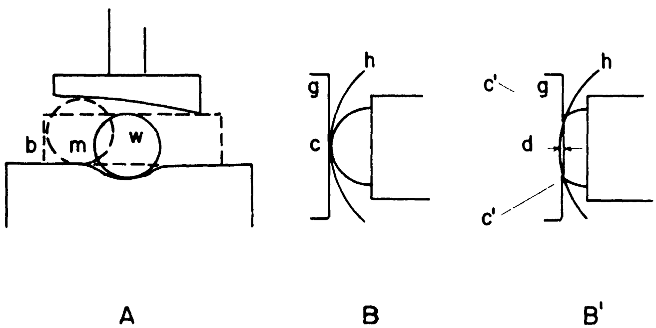


Fig. 11. Typical errors produced by anvil and contact wear. View A shows effects of wear when comparing work (w) with masters (b) and (m). A difference (d) in measurement, as in Views B and B′ may be due to worn contacts.

Fig. 11. A comparator is mastered with either a flat gage block *b* or a cylindrical master *m* and then an attempt is made to check the diameter of a cylindrical work-piece *w*. When the flat surfaces of the contact and anvil are not parallel or hollows are worn in them, an accurate comparison cannot be obtained.

The error produced by a spherical contact which has been allowed to wear flat is shown in Views B and B′. When an unworn contact is used to caliper an internal diameter *h* and then is used to compare it to the flat, plane surface of a gage-block caliper *g*, there is no loss of dimension at the point of contact *c* (View B). But when the spherical gage contact is worn (View B′), it bears against the gage block as shown and against the hole at points *c* and c^1. The dimensional loss due to wear — the error in obtaining the true diameter of the hole — is equal to the distance *d*.

The extent of wear hollows in anvils and lack of parallelism can be readily measured with optical flats. The spherical contact can be checked by examination with a microscope. The contribution to measurement error from internal instrument wear is shown if the instrument is calibrated and lack of repetition is observed.

Wear and dirt inevitably appear together. One way to control wear error is to keep gages, masters, and work-pieces clean. However, even with perfect cleanliness, some infinitesmal amount of wear takes place with each gaging. Some materials increase wear. Carbide masters are wear resistant themselves, but can raise havoc with hardened steel anvils. Cast-iron work-pieces present the problem of sand particles and glass-hard cooling checks. All surfaces should be completely clean and free from lapping and buffing compounds.

The question is frequently asked: How often should a gage be checked for wear — how many gagings can be made before the error from wear becomes appreciable? Making steady checks for wear, keeping a record of them plus a count of the number and type of gagings completed between checks — recorded experience, in other words, and not the personal opinion of an individual — becomes the answer.

Where measurement is a matter of detecting a size difference of a millionth or two, contacts, anvils, gage blocks, and masters have to be replaced or renewed the instant any wear at all is discernible. However, for most commercial precision measurements in the neighborhood of 5-, 10-, 20-, or 50-millionth increments, a "wear allowance" of up to 5 per cent of the tolerance is often permitted. Where the amount of wear is constantly known, measurements may be corrected for it arithmetically to arrive at the final correct figure. Corrections for instrument or meter wear are usually made in this fashion, especially in

cases where careful calibrations have, in particular, shown the extent, location, and direction of such errors.

Gage anvil and contact material is also important. Unhardened surfaces are almost completely unreliable. Chrome-plated parts seem to withstand ten times more wear than those of unplated, hardened tool steel. (When chrome is used against chrome, however, there is a possibility of galling.) Carbide blocks, masters, anvils, and contacts, usually repay their initial higher cost by providing from 100 to 1000 more wear-free gagings than those of hardened and tempered steel. Sapphire-tipped contacts, although subject to breakdown, usually wear about as well as those of tungsten carbide, but diamond contacts, of course, set the endurance records. It must be remembered, however, that even diamonds do wear down, and the inspector cannot be complacent about checking the condition of such contacts periodically.

The Importance of Correct Manipulation

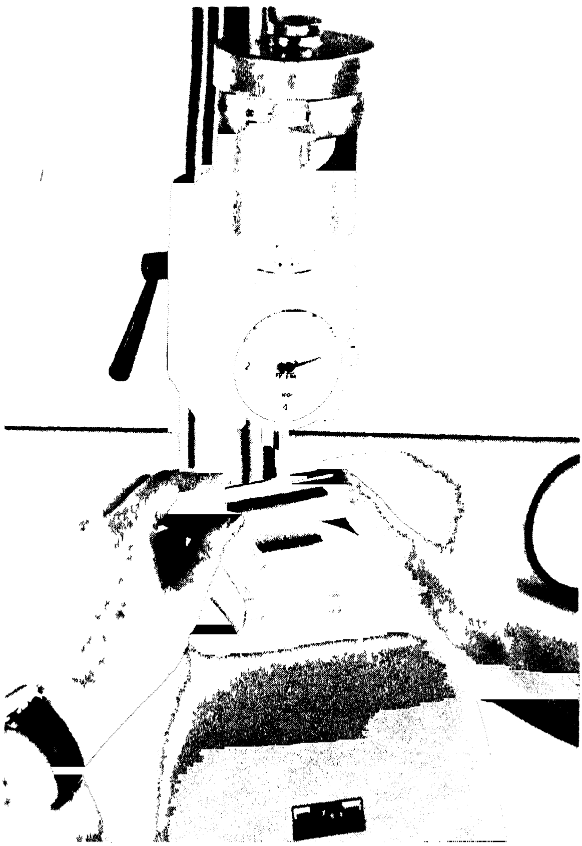
The effect of manipulation in breeding errors, or in correcting them, has been implied in several of the preceding cases. For one example, forceps or tweezers, and gloves or pads, are used to keep the heat of hands away from the work. Intelligent checking for looseness and constant, thorough cleaning are other important phases of manipulation to be carried out in millionth-inch measurement.

No doubt, the first rule of correct manipulation would be to use the hands as little as possible or, to put it more positively, take the hand off the work as soon as possible. Let the gage do its own work! For some reason, inspectors tend habitually to use one hand, or both of them, as a vise and never let go while sizing a part. Most gages are designed to hold the work properly, and once they are placed in the prescribed position, they will be more likely to give the correct measurement.

Cramping is the term often used to describe this tendency to hold the work rigid. The mechanic who uses an indicating micrometer for the first time quickly realizes how often he may have forcibly, though unintentionally, held the work and the micrometer at a slight angle to each other, enough sometimes to produce a half-thousandth-inch measurement error. Another example of potential cramping is seen in Fig. 12. As long as the inspector's fingers cling to the ends of the cylindrical master, he will be inclined to tilt it, twist it, or hold it out of true geo-

metrical position and thus introduce several millionths of an inch error in his reading.

True, the cylinder shown in Fig. 12 must be positioned so that its full diameter and not a chord is fully under the gage contact, but when it seems to be properly centralized, both hands should be removed while the indicator or meter is read. The operation should be repeated several times for confirmation of true centralization and the reading. Some inspectors have formed the worthy habit of lightly tapping the cylinder back and forth under the gage contact with a pencil, until repeat readings indicate it is exactly centered.



Courtesy of Federal Products Corp

Fig. 12. Hands often unconsciously tend to "cramp" work out of correct gaging position. Both hands should be removed from the work-piece while the indicator or gage is read.

Keeping a grip on the work-piece is sometimes excused because the work-piece overhangs the anvil — the unbalanced weight might cause it to tilt indiscernibly against the gage contact pressure and result in measurement error. This is good thinking except that it is probably better to secure a wider anvil. Hands invariably tremble, but the work-piece must not flutter. Often it pays to design and have available some sort of auxiliary holder for the work-piece. Clamps and magnets are handy devices.

Since gage blocks are widely used as masters, their continually correct manipulation is important. Experience has shown that carelessness about wringing gage blocks together and to anvils readily produces errors as great as 100 millionths (0.0001 inch). On the other hand, experiment indicates that proper wringing may possibly create an error no greater than an immeasurable fraction of 1/10 millionth inch.

Perfectly flat, perfectly clean, dry gage blocks are sometimes difficult to wring. Many inspector apply a little "wrist oil," but this expedient should be positively taboo where less than 5 millionths of an inch are involved. An extra-light, filtered clean, kerosene-like oil, coated on the block or anvil so thinly that it is iridescent, produces no discernible error. A 1-inch, smooth cube of basswood kept soaking in a covered container of clean kerosene can serve as an applicator.

Prior to use, it should be lifted out with tweezers, grain end up, onto a piece of clean tissue or cloth to let the excess oil drain and evaporate. A gage block rubbed once across with the end grain of the oiled basswood cube will have almost exactly the right film of lubricant on its surface for error-free wringing.

A man could not be expected to work at precision measurement day in and day out without occasionally dropping a gage block, master, or work-piece. Such an accident is bad enough, but humans seem compelled to conceal personal clumsiness. Consequently, the fallen object is retrieved as rapidly as possible and put to work with an innocent air of its never having been dropped. After such an accident, the fallen part should be carefully examined for dirt, nicks, scratches, dents, or distortion. Any injury should be repaired or the piece replaced before making further millionth-inch measurements. Gage extensions, accessories, and anvils roll or slide readily off benches. If an attachment contains a diamond or sapphire insert, it should be checked with a microscope for breakage.

Clumsiness and awkwardness, though unintentional, are the opposites of a certain adroitness and dexterity required in millionths measurement. It is good practice to complete a setup and take one or two readings simply as a sort of rehearsal. Such a custom not only permits a critical analysis of the measuring method, but also gives the inspector extra practice toward the manual deftness desired.

The word *flinching* is frequently heard in inspection circles. While one dictionary definition describes it as a loss of nerve in the face of an unpleasant duty, the "trade" use of the word signifies more a subconscious tendency to make a gage read what is desired rather than the true dimension, especially in marginal cases. The finger pressure exerted on a micrometer spindle readily varies to accommodate a more desirable reading. The added leverage of tweezers makes it easier to cramp a piece into a more favorable position under the comparator contact. Inspectors readily miscount a dial division or two to get a subconsciously desired reading. Flinching is an unintended human observation in measurement that lies in the borderland between manipulation and approximation.

Approximation Should Be Shunned

Many like to guess, estimate, and round off numbers, and these traits tend to subvert the exactness required in millionth measurement. In Chapter 5, the estimating of an exact size is discussed. The text suggests the use of a scale of finer discrimination or, to use more modern terminology, of greater resolution. If a micrometer reads 0.494 inch plus something, use the vernier scale to read that exact 0.0004 inch. It is better to give the complete, correct reading of the dimension as 0.4944 inch, rather than guess that the final figure is, say, 3 "tenths," or something else.

The minute a marker reads between graduations on any instrument, the desire to estimate its position becomes practically irresistible. In millionths measurement, it is safer to name the graduation next higher or lower, the one closer to the meter hand, rather than to try to estimate half a scale division. In Fig. 13, which would be the correct decision — to call the marker halfway between *a* and *b*, or to say it is more on the side of *a*? Probably few would call the measurement as size *b*; the majority would vote for *a* plus a half; the others, battle-scarred from many measurement errors, would refuse to estimate but would

arbitrarily settle for graduation *a* as the size, especially when each graduation represented a difference of only 1 millionth of an inch.

At the present state of the art, no one (including the National Bureau of Standards) is yet 100 per cent positive of accurately measuring a size difference of a fraction of a millionth. An instrument might seem to show such a variance, but instrument error can be greater than the actual size difference. A millionth can be "blown up" to look like an inch, but all the inherent errors are seen in proportion.

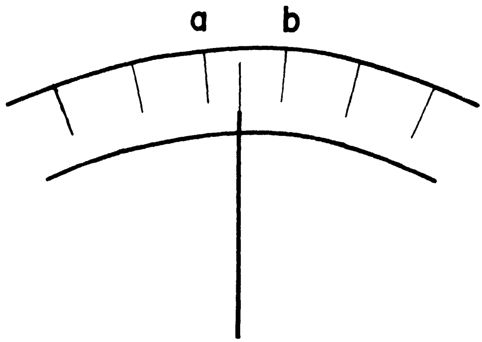


Fig. 13. An opportunity for approximation. When each graduation represents a millionth of an inch, estimating to a fraction of a division is unwarranted.

Another misleading habit is to average a group of readings and call the result the true work-piece size. If there were, for instance, two readings of a gage-block thickness, one of 0.120001 inch and the other of 0.120002 inch, the tendency would be to call the block size exactly 0.1200015 inch. Almost without exception, measurements reported to the seventh decimal place represent an arithmetical average and not an absolute measurement.

Currently, the recommendation is to take several successive readings which are then averaged and their standard deviation* calculated. The measurement is reported to be possibly as high as the average plus three standard deviations, and very probably no higher, or as low as the average minus three deviations, and very probably no lower. Where the exact size might lie

* The statistical technique of procuring and using the standard deviation is described in *Quality Control and Reliability*, N. L. Enrick, INDUSTRIAL PRESS INC., New York City, 1966; and in other standard statistical reference books.

between these plus or minus limits is purely a guess. A further analysis of a group of figures, however, sometimes influences a statistician to make an "educated" estimate. Repeated similar readings in a series are about the best guide to the exact measurement, although, to be doggedly pessimistic, a recurring (systematic) error either in the apparatus or in manipulation can invalidate the result.

Anyone regularly reading instruments must understand parallax and appreciate the extent of error its neglect can produce. To avoid parallax, view the meter hand normal to the graduations. Never trust an oblique, careless glance. Nullifying parallax is actually very much a part of correct gaging manipulation.

"Round" Holes Are Seldom Round

In millionths measurement especially, the inspector might as well resign himself to inevitably finding some degree of "relationship" trouble, usually involving a combination of misshapes grouped together on one piece. Luckily any lack of squareness, parallelism, roundness, or other geometric discrepancy can be measured and the direction and amount present counteracted by correcting the final size readings.

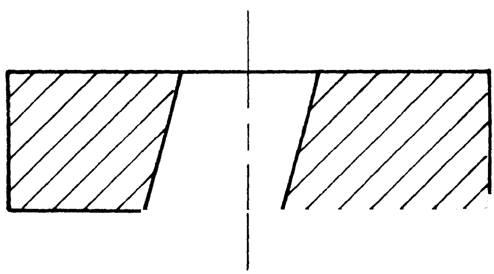
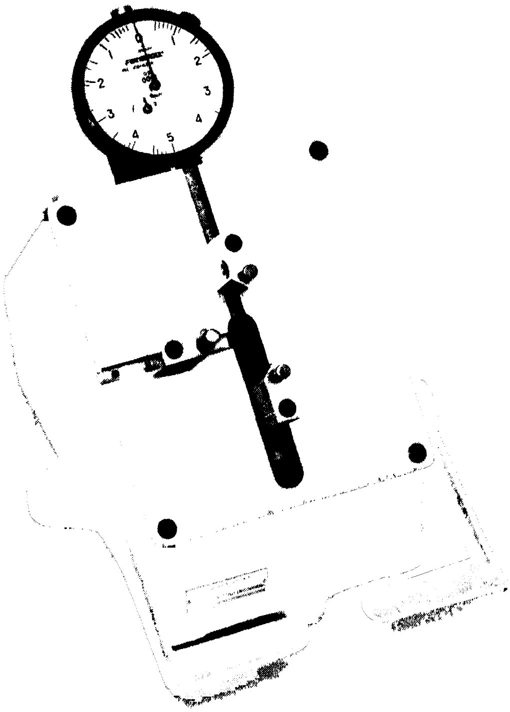


Fig. 14. "Lean" in an otherwise perfect hole is difficult to detect when the error is only a few millionths of an inch.

Gage blocks whose end surfaces are consistently smooth, flat, and parallel are available. In the case of cylinders and holes, the situation is different. Probably no pieces having these geometric forms are ever entirely free from some combination of measurable ovality, taper, waviness, or barrel or hourglass shape.

Until tolerances are down in the 10-millionth-inch range, a hole with a condition like that sketched in Fig. 14 does not cause

assembly difficulties too often. How would an inspector go about checking for a leaning hole whose diameter was just about perfect, as well as being free from other geometrical errors? How would he be sure of finding the condition illustrated when the error in inches is only a matter of 3 or 4 millionths of an inch or involves only a few seconds in angularity?



Courtesy of Federal Products Corp

Fig. 15. This gage with three sensing jaws is suitable for detecting three-point out-of-roundness in a hole.

Millionths measurement reveals another hole condition which may never have been detected in holes made and measured to more ordinary tolerances. The geometric irregularity is triangular out of round, or "cloverleaf." Most inspectors have encountered these peripheral characteristics which are peculiar to centerless-ground cylinders. But how, they ask, do such ef-

fects occur in a hole? Nevertheless, triangular out-of-roundness does show up in holes to prevent close-tolerance assembly fits and confuse results in two-point, millionth-inch calipering.

If the quill that holds a grinding wheel, or any related revolving shaft on an internal grinder, happens to have been centerless-ground, and if its cloverleaf condition is ignored, the shaft's triangular out-of-round pattern will somehow be implanted to some degree on the periphery of the hole being ground. The condition is seldom detected until control of hole geometry in millionths of an inch is needed. Even then the effect will never reveal itself under two-point, inside-diameter calipering. It can be detected and measured to some degree if the hole is checked over a three-jet air plug or on a three-point internal comparator of a type similar to that shown in Fig. 15. The latter must be equipped with an indicator, transducer, or an air cartridge device having a resolution of 50 millionths (0.00050 inch) or even finer.

A Discussion of Lobing

The foregoing is merely an introduction to a whole field of measurement geometry which has been given little attention where parts tolerances are never smaller than 0.0005 inch. Out-of-roundness and cloverleaf, along with taper, barrel shape, and hourglass profile on cylinders and in holes, became of greater concern as tolerances narrowed to 0.0001 inch. When size control to within a few millionths inch loomed as a requirement, out-of-roundness error became very important.

Until lately, the term *out of round* in a machine shop has meant almost any condition that might show up on a test indicator—eccentricity, bend, warp—and, in particular, plain ovality. Similarly, an out-of-round hole was considered to be only egg-shaped with respect to the major and minor axes. Nowadays we know that there is more to it.

Lately, also, a sort of double ovality has been recognized where the work-piece seems to have two major and two minor axes. In Fig. 16, simple ovality is seen at A and ovality occurring in two directions is illustrated at B.

From the observation of such conditions has grown the terms lobe or lobing. In fact, industry is recognizing that no hole, cylinder, or sphere probably ever possesses a geometrically perfect, symmetrical round shape. Nor does it but seldom assume a perfect oval (two-lobe) shape. The profile of the average

machined cylinder or hole (and sphere) varies, in terms of millionths, from something completely distorted and irregular to, usually at best, a multiple-lobed, fairly symmetrical outline. Even then it often exhibits much waviness, chatter, and surface roughness.

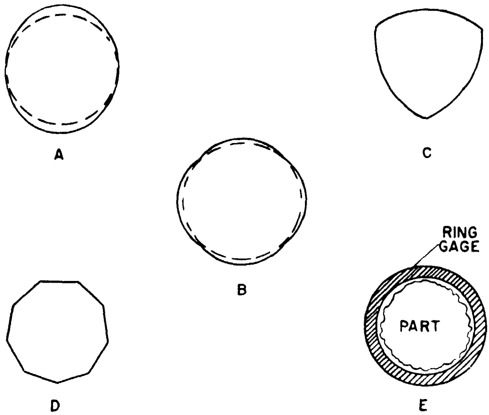


Fig. 16. Diagrams illustrating a few of the actual profiles of machined cylinders or holes often supposed to be perfectly round. Lobing and waviness are greatly exaggerated in size.

The familiar three-lobed shape common to centerless grinding is seen at C, while diagram D pictures the sort of multiple-lobe shapes that are far from uncommon. Finally, sketch E illustrates cylindrical surface waviness and surface roughness of a work-piece, as well as some out-of-round distortion and with possibly a trace of lobing also being present.

The diagrams in Fig. 16 have one necessary exaggeration. The actual dimension of the amount of lobing seen at A, B, C, and D is usually mostly a matter of millionths. Occasionally, it can equal 0.0001 inch, 0.0002 inch, or more. (Sometimes the distortion, ovality, or lobing is visible to the naked eye.) The cylinder or hole diameter is shown nearly full size, but the lobes are magnified some 10,000 times to make them visible. In other words, the diameter might be, say, 3 inches but the lobing might be only 30 millionths inch though it looks to be sizable in proportion to the diameter.

Though lobing (ovality), distortion, waviness, and roughness may change the periphery of the shaft or hole from the desired perfect circle by only a few millionths, it is still these very conditions that cause hum, vibration, heating up, and wear. These

effects, in turn, increase to cause noise, rattle, and finally the failures much too common in industry.

Some of the Causes of Lobing

Probably the centerless grinder did more to focus attention on lobing than any other single factor. But out-of-roundness can be produced in many ways. Drive shafts and bearings in lathes and grinders, if they are not truly round, to some degree impress their patterns of peripheral irregularity on the work, whether a hole or a cylinder is being machined. Centers that are out of line may produce similar effects. Three-jaw and multiple-jaw chucks no doubt cause many work-pieces to become out of round. In recent years, magnetic chucks are coming more into use, since they are often able to grip work-pieces without distorting them. The springing of metal under cutting pressure also probably contributes to lobing. All causes of lobing are not known at present. The important matter, however, is to detect, analyze, and measure lobing as a first step toward eliminating or minimizing it.

One more point is important. If distortion, out-of-roundness, or ovality, or lobing (even waviness sometimes) has been established on a cylinder or in a hole or ring, subsequent operations cannot be depended on to eliminate any of these conditions completely. The distortion pattern set up by the roughing lathe will usually show up after grinding, though the degree of error may be reduced to millionths of an inch. Lobing is, perhaps, the most persistent in this respect.

Measuring Lobing

The plain elliptical form of out-of-roundness (what might be called two-point lobing) is readily detected by turning the piece on the platen of a comparator under some form of indicator with adequate resolution. For that matter, any type of indicating caliper or snap gage may be used. The oval hole responds to the dial bore gage or internal measuring machine as seen in Fig. 8. The rarer case of four lobes (or any even number of lobes) can be checked by the same sort of two-point measurement.

Many inspectors, however, have experienced the mystery of precisely "miking" a shaft only to discover it would not then assemble to a hole or ring gage that is very close to the same diameter. The reason is that measuring devices having dia-

metrically opposed contacts do not measure the "envelope" or complete circumference and cannot, therefore, detect odd-numbered lobes, as well as some forms of distortion and waviness. A ring gage does "envelope" the periphery of a cylinder (View E, Fig. 16). A plug gage acts similarly in a hole. Plug and ring gages will tell whether a shaft and bearing will assemble without interference, though there may not be a very good fit from the point of view of wear and noise, as View E suggests.

Why a shaft with lobes will not enter a truly circular hole of similar diameter is illustrated in Fig. 16. Also — and this is often hard to believe — a shaft with the shape shown at C will roll just as smoothly on a flat surface as a perfect cylinder. Multiple-lobe pieces show the same general characteristics and their lobing is equally unmeasurable by two-point methods if there is an odd number of lobes and if the lobing has a symmetrical geometrical arrangement.

To detect lobing and count the number of lobes, use of a V-block is recommended. Ordinarily, the standard, 90-degree included-angle V-block will do. But to measure the exact amount of the lobing protruding, $R - r$ (Fig. 17) requires a V-block with a special angle. This correct angle A can be calculated from:

$$2A = 180 - \frac{360}{n},$$

where n equals the number of lobes. For a three-lobe configuration, A becomes 30 degrees and the V-block used should have a 60-degree included angle. The measurement M, which is

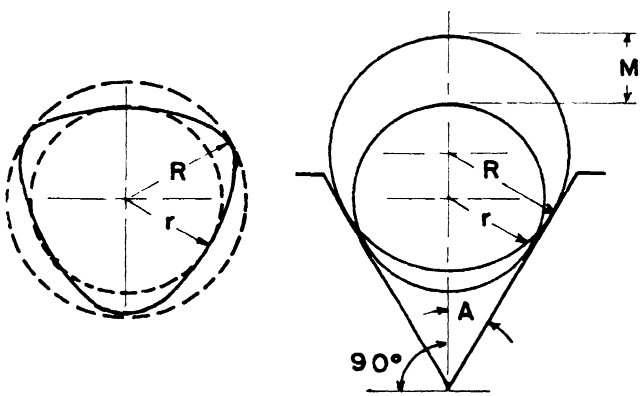


Fig. 17. Measurement of the exact amount of lobing requires a V-block with a special angle (A). Here illustrated is the geometry involved.

obtained by revolving the "round" piece in the V-block under the comparator contact, can be converted to a measure of the radial variation in cylinder contour by means of the formula: $M = (R - r)\ (1 + \operatorname{cosec} A)$.

If the discrepancy from true form is to be analyzed in terms of millionths, attention must be paid to the V-block. The two-plane sides should be checked for flatness and wear from time to time and surface roughness of the two areas should be at a minimum. The vee angle must be known to be unchanging throughout the length of the V-block, and the center line of the vee must be perpendicular to any gage platen on which it rests — truly 90 degrees, as indicated in Fig. 17.

If a cylinder were mounted in a V-block under the contact of a comparator, the latter set to zero on it, and the cylinder

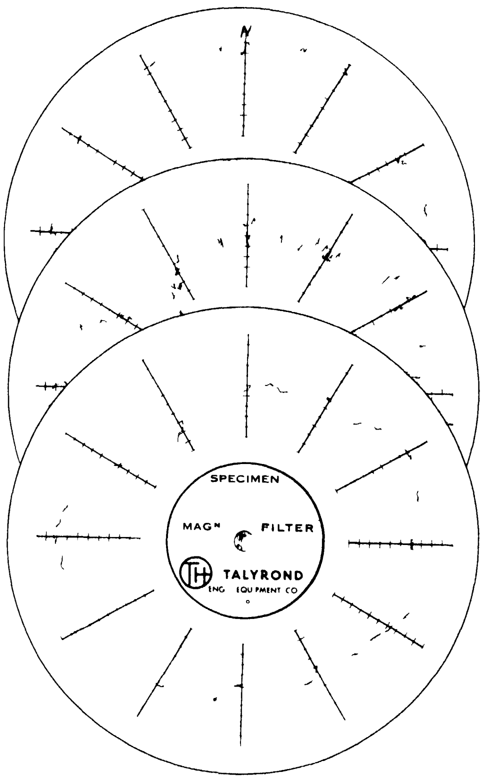


Fig. 18. Specimen charts which show, in millionths of an inch, actual roundness, surface waviness, and roughness. The chart of a perfect piece (which does not exist) would be a perfect, smooth circle. The charts do not record diameter.

revolved, say, 5 degrees at a time, a series of plus and minus readings would be observed. If these readings were plotted around a sort of circle chart, a wavy outline would be completed that would be similar to that shown at E Fig. 16 or those in the

Courtesy of Engis Equipment Co

Fig. 19. An electronic instrument which detects and records deviations from perfect roundness.

charts illustrated in Fig. 18. To perform the same measurement on the surface of a hole is another story. For this purpose (and also to get an external profile rapidly) special instrumentation is helpful.

Several types of roundness measurement apparatus are available, and the inspector should get acquainted with the tech-

niques and details involved. Their basic principle is not unlike the mechanism of a jig borer which permits a circular sweep. One type, illustrated in Fig. 19, has a precision spindle, which runs true within 0.000003 inch, as its principal feature. An attached stylus pickup contacts the specimen as the spindle rotates. What the stylus "sees" as it sweeps the exterior of a cylinder or the inside of a hole is transmitted electronically, amplified, and recorded as a polar diagram on a chart. (Sample charts are also shown in Fig. 18.)

This kind of instrument gives no indication of the work-piece diameter; it simply measures and charts the plus and minus deviations of the work-piece periphery from a true circle. Ingenious electronic filters permit separation of roughness and waviness values from those of lobing and general contour, if desired. A caliper stylus and work-table arrangements permit studies of such features as concentricity, parallelism, and squareness. (The instrument shown will also detect and measure the "leaning" hole illustrated in Fig. 14). In another type of instrument, the "sweep" is gained by revolving the work-piece against the stylus, which is held rigidly by the gage.

The Gaging Setup Should Be Square

An important part of the geometry of measurement is the four-square construction required of gages and gaging setups. A try square is an important tool for the metrologist.

It has been suggested previously that flat anvils must be checked regularly for the exacting flatness required of them. Similarly, if flat anvils are supposed to be parallel to each other, that necessary condition should be appraised by rolling a small precision cylinder or ball between them or, much better, by slipping an optical flat between them. The idea of examining the profiles of spherical contacts has also been suggested.

There is a tendency to overlook the matter of perpendicularity, or the lack of it, and to assume that the gage will surely be at right angles when placed on its platen. The desired condition is shown at A in Fig. 20. A comparator or gage should be carefully checked for squareness from several different angles and at either end of its travel to be sure that the ideal condition prevails — with the gage clamped tight!

In direct measurement, the condition seen at B in the same illustration is obviously unwanted because measurement h is greater than dimension u (View A), and the difference between

h and u increases as angle a increases. The relationship between h and u is shown in View C.

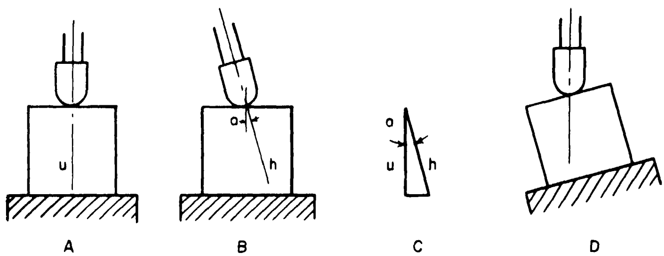


Fig. 20. Perpendicularity in gaging setups should not be assumed in millionths measurement. An angular error of 1 minute can cause a 10-millionth-inch error in 1 inch.

It should be realized that all errors of perpendicularity are not due to gages. A sizable number of them are the result of crooked setups. Furthermore, even though the gage head and contact could be perfectly perpendicular, the reference anvil might be tilted a trifle, as indicated in View D.

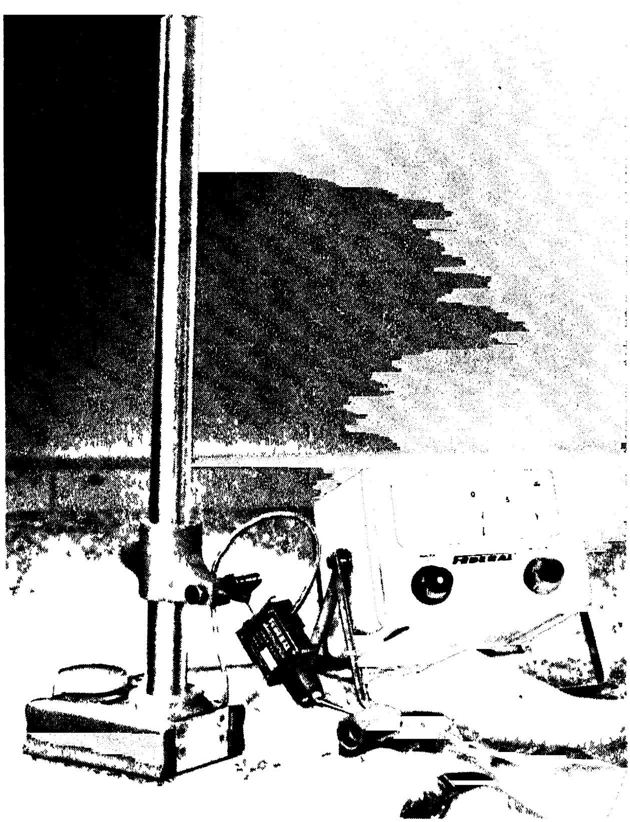
The Surface Plate in Millionth-Inch Measurement

Traditionally, the surface plate has been the basic reference surface, so much so that many inspectors are reluctant to adopt other techniques. Setups of the sort illustrated in Fig. 21 seem natural to them, but to make a similar length measurement with a modern precision calipering gage or even with a comparator is considered not quite legitimate. Although instruments like the one seen in Fig. 21 are available commercially having resolutions of at least 5 millionths inch, there is considerable doubt whether a height gage on a surface plate can take advantage of such fine readings.

An old surface plate could more resemble a strip of rolling prairie when its surface flatness is considered in terms of millionth-inch measurement, and the underside of a height gage shoe is also likely to be no paragon for flatness. Although either condition could be considerably corrected, too often they are overlooked because surface-plate setups unfortunately give a false sense of security. Even at best, probably only very few, small areas of a surface plate would show as little as 10 millionths inch of unevenness. As a result, work-pieces, height gages, and other equipment tend to tip or teeter at least minute amounts.

For ultra-precise measurement, everything should rest stably on the surface plate. The iron surface plate is useful because equipment with a magnetic base will hold tight to it. The traditional custom of sliding the gage back and forth should be avoided in millionths measurement; it is better to move the work-piece under the gage contact, rewringing it where possible.

As a working area, the level, solid surface plate does fill a valuable place in millionths measurement. It can form a dependable foundation on which to fasten precision instrumen-



Courtesy of Federal Products Corp

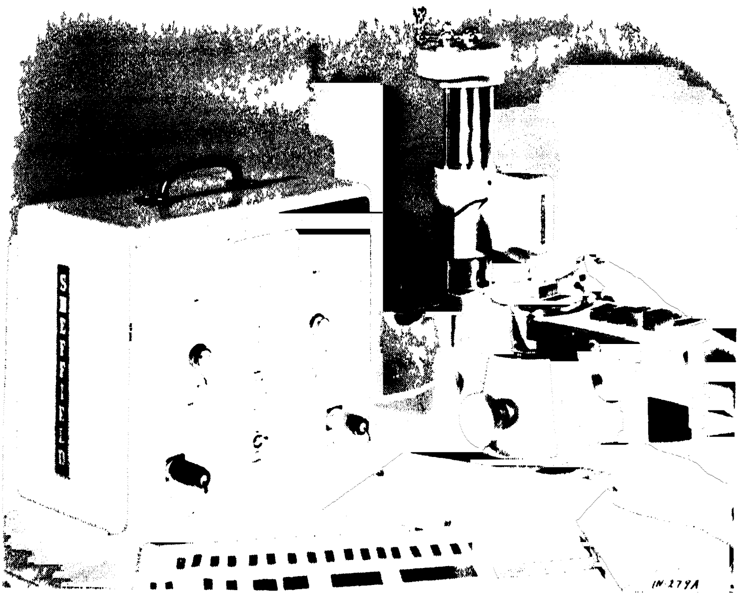
Fig. 21. A surface plate setup in which an electronic instrument is being used to make measurements in the order of 10-millionths of an inch.

tation. It is useful as a heat sink; it reduces and often nullifies vibration; it seems to urge the inspector into a more orderly, cleaner, and professional arrangement of his work.

Procedures for Checking Gage Blocks

Gage-block checking is almost the most important phase of millionths measurement. The average plant may not yet have too many occasions to inspect parts with tolerances closer than about 20 millionths inch. But gage blocks must be used to master, set, and check the production gages — to check master ring gages, for instance. Gage-block checking, thus, becomes a necessary routine. If gage-block inaccuracies are unknown, all other measurements stemming from them will be undependable.

Many plants are equipped with electronic comparators capable of measuring to a millionth inch and are especially suitable



Courtesy of Sheffield

Fig. 22. This millionth-inch comparator, especially designed for gage-block checking, has opposed contacts.

for gage-block calibration. The comparator shown in Fig. 22 has opposed contacts which eliminate the need to wring the blocks to an anvil and are also excellent for checking thin blocks, as can be seen in Fig. 23. A few companies have and

use interferometers, the basic equipment for gage-block calibration. These instruments are briefly described later.

Comparators require less capital investment than an interferometer and are in more general use for checking gage blocks. But there must be available at least one complete set of "master" or "laboratory" gage blocks, with an accompanying and periodically revised calibration chart. This set is used only for recalibrating the blocks in one or more "inspection" grade sets. These latter blocks, in turn, are used for workaday checking of other blocks, of cylindrical and ring masters, and occasionally to calibrate instruments and gages.

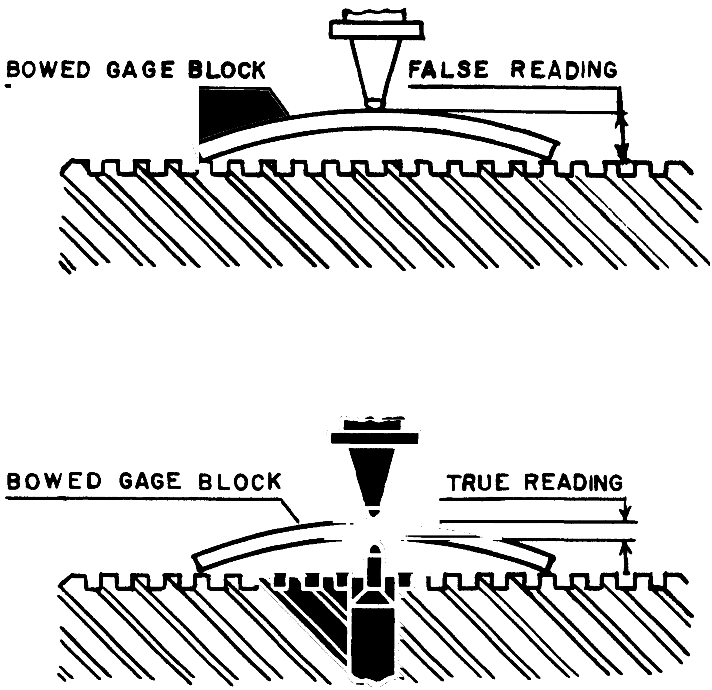


Fig. 23. Dual gaging contacts are advantageous, since thin gage blocks tend to warp when not wrung together.

Master sets should be sent to the manufacturer (or perhaps to the National Bureau of Standards) periodically, but not less often than once a year, for recalibration. New, calibrated blocks should be purchased to replace any that show much more than plus or minus a few-millionths-inch error in length; or an equal or less amount of error in flatness or parallelism. Though a

plant may be equipped with an interferometer to do basic calibrations, it is better occasionally to obtain conformation from another source.

Several preparatory steps are needed before actual calibration of any block. First, the block should be clean and grease-free, and its surfaces and edges checked for scratches, pits, and nicks — damage which often means raised metal. An optical flat should be used to determine if any such nonconformities are present.

Some sets of gage blocks come equipped with small, flat deburring stones for smoothing surfaces and edges. A block that needs stoning should not be used. Adequate coaching on how to do stoning without wearing or injuring the gage block is a prerequisite for performing the deburring operation.

The surface roughness of blocks should also be measured and known. Ordinarily roughness is of such slight magnitude that use of a stylus type surface recorder with a high-resolution probe or an interference microscope is necessary. The purpose is to be sure that peaks of surface roughness are not present to cause damage during wringing and poor wringing. Narrow peaks due to excessive roughness may be flattened down after the blocks have been wrung together once or twice, causing a measurement error. For the latter reason, the surface condition at the tip of the spherical contact of the comparator should be examined with a microscope.

Next, the flatness of both end surfaces of the gage block should be checked with an optical flat. (This is discussed in Chapter 11.) If surface irregularity is apparent from the contours of the fringes, its magnitude should be estimated.

The distance between any two fringes appearing on an optical flat represents close to 11.6 millionths vertically. This is true whether there are many lines close together or a very few wide apart. Characteristic edge wear is illustrated at A in Fig. 24. A straight line can be imagined drawn across the dips in a fringe as at e-e'. (This operation can be simulated physically by laying the straight edge of a transparent plastic rule across the optical flat from e to e'.) The question then is: What proportion of distance f (which represents 0.0000116 inch), is distance d? The latter might be estimated as $\frac{1}{8}$ of f or as a rounding downward at the block edge of approximately 1.5 millionths inch (arithmetically, $\frac{1}{8}$ of 11.6 is 1.45).

A little edge wear on blocks can be tolerated. However, a

characteristic wear condition that cannot be overlooked is shown at B in Fig. 24. The depth of the depression *d* in the sketch at B must be estimated. As drawn, it would seem to be

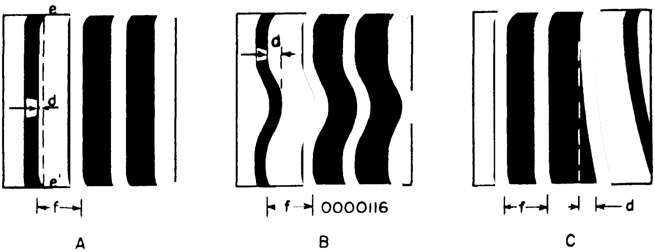


Fig. 24. Estimating the extent of various faults encountered in checking gage blocks by means of optical flat fringe contours. The conditions shown are: rounded edges (A), a depression (B), and a sloping area (C).

close to half of 11.6 millionths, or about 5 millionths inch. Illustrated at C in Fig. 24 is still another condition. There, the fringes show that the block has a flat area that recedes by an amount *d* that might be estimated as around 7 millionths inch.

If a contour pattern indicates either hollows or humps on gaging surfaces, it is good practice to sketch their contours on paper for reference. Where difficulty like that described at B, Fig. 24, appears on both gage surfaces, an enlarged cross section of that block might look somewhat like the condition shown exaggerated in Fig. 25. If such a block were wrung on a comparator anvil, the comparator, depending on where the spherical contact touched the block, would register: (a) at the nominal

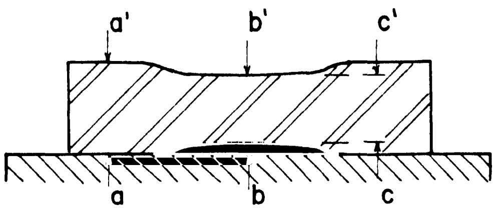


Fig. 25. A possible cross section of a worn block shown greatly exaggerated. Measurement of this block would result in one of three readings representing distances (a-a'), (b-b'), or (c-c'), depending on the gaging method.

thickness of the block (*a-a'* in Fig. 25) or (b) at the incorrect thickness *b-b'*. A gage with calipering jaws could register *c-c'* rather than *a-a'*. Hence the desirability of a contour sketch. It is also convenient to use the manufacturer's legend stamped on

the blocks as a means of always obtaining the same orientation and the same end up, when taking a series of measurements of a block.

Taper or lack of parallelism between the gage-block measuring ends is also a condition ordinarily checked as a preliminary to millionths measurement. The usual practice is to move the block in one direction under the millionth comparator contact and then explore through 90 degrees the other way. Any relevant change from a zero meter reading is observed and the direction and the extent of any taper present is marked on the contour sketch.

Since the gage block under question will be compared to a corresponding master block, the latter might be rechecked for flatness and taper. At this time also, all preparations in connection with obtaining proper environment and for avoiding the many types of measurement error previously described should be completed.

The gage-block comparator is set to zero by means of the master. This operation is repeated and the comparator reset until the inspector feels confident that it will hold its zero setting while the master is removed and the block being measured is slipped into place.

Another rule for checking blocks is that measurements always should be made at the same point on the block. The dots on the blocks seen in Fig. 26 are located where it is common practice to have the comparator spherical point make contact. The posi-

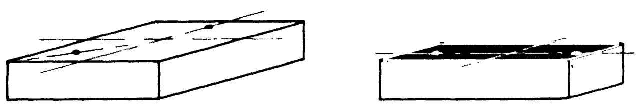


Fig. 26. Locations on gage blocks where, in common practice, contact with the spherical gaging point of a comparator is frequently made. All block measurements should be taken at the same point.

tion of thick and thin spots and taper could make some other points the choice. The choice of gaging location is also influenced by the type of reference anvil used.

Generally speaking, three types of comparator reference anvils are employed for gage-block checking. A smooth, perfectly flat anvil of the sort seen in Fig. 1 has many proponents. Some inspectors believe that greatest consistency and reliability

in millionth-inch measurement are gained when a gage block is correctly wrung to such an anvil. Their claim is hard to disprove. On the other hand, either there is a possible error from heat transfer (though the block is wrung with gloved hands) or there is a time loss in taking each measurement, while the inspector waits for the block and anvil temperature to equalize.

Others seem to have confidence in a three-ball arrangement like that suggested at A in Fig. 27. Precision bearing balls are carefully inspected for flat spots. Since they are seldom completely spherical, often exhibiting several millionths out-of-

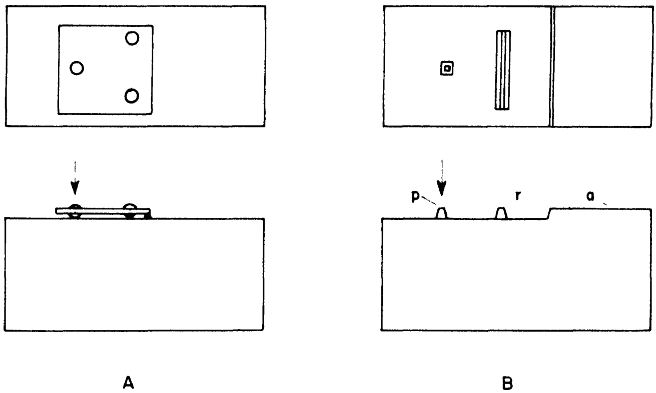
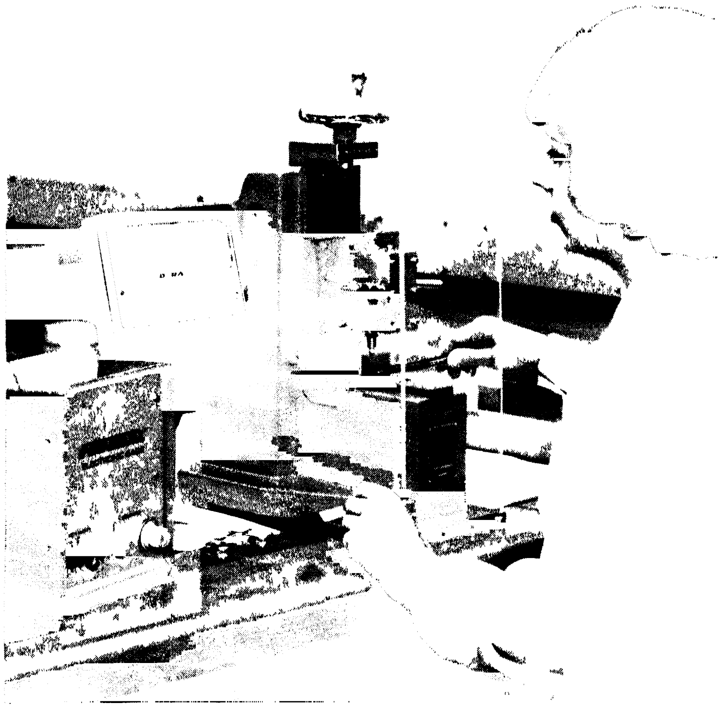


Fig. 27. A three-ball anvil (A) arranged for checking gage blocks should have one ball directly under the comparator contact as shown by the arrow. Alternatively, pin-and-rail anvils (B) are used.

roundness, each ball should be explored dimensionally. The three balls are then placed on the anvil, with selected, equal diameters, positioned vertically. The custom is to harness them with a thin fiber plate (View A, Fig. 27) kept in position with a spot or two of sealing wax. Usually the ball group is arranged on the anvil so that one ball (at the apex of the triangle) is directly under the comparator contact. One of these anvil setups is shown in use in Fig. 28.

There are some who favor the "pin-and-rail arrangement such as that seen at B in Fig. 27. The pin does not present a spherical surface for contact but instead has a flat land of about 1/64 inch in width. The rail is also about 1/64 inch wide. Both lands must be straight, flat, and on the same level plane. One practice is to machine away portions of an anvil to provide a profile like that illustrated at B. Initially, and from time to time,

surfaces p, r, and a are lapped flat and level, with surface a used as the reference surface for this operation. The spherical gaging point should approach the block surface in a truly perpendicular manner, contacting it immediately above the center of the pin, as seen at B.



Courtesy of Federal Products Corp

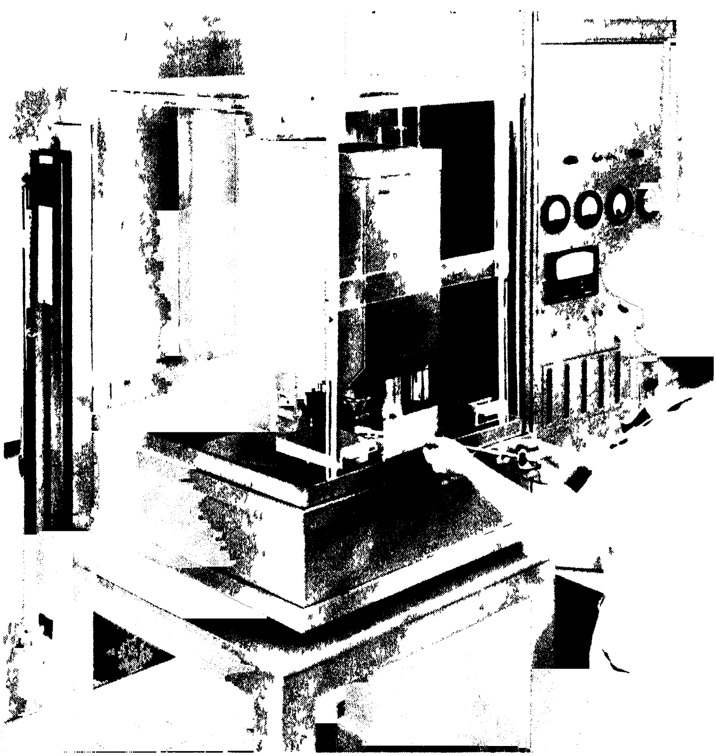
Fig. 28. Three-ball anvils are shown set up in a typical arrangement for measuring gage blocks on a millionth-inch comparator

Measuring Length with Interferometry

The basic way of determining any gage-block size is by a count of a number of light waves by means of an interferometer. The new international standard of length, adopted the latter part of 1960, is the wave length of the orange-red light of krypton 86, of which there are 1,650,763.73 in the international meter. (One such wave length thus equals 6057.802×10^{-7} millimeter.) This makes the inch exactly 25.4 millimeters. Since interferometry is an extensive science, a treatment of the subject here is necessarily very brief.

Interferometers as instruments for measuring length have been developed to a sufficiently practical stage to permit their daily use as an inspection method in the hands of competent people. The inspector who may be called upon to use interferometric methods is urged to make as extensive a study of the subject as he can. For a start, he can acquire considerable education in the theory, principles, and use of interferometers from manufacturers and suppliers of such equipment, as well as from gage-block manufacturers.

One such type of apparatus is generally known as a fringe-count micrometer; and another type (laboratory models of which have been in use for a number of years) is generally known as a gage-block interferometer. The fringe-count mi-



Courtesy of Link Div., General Precision, Inc

Fig. 29. A fringe-count micrometer and electronic fringe counter. The specimen is introduced through a self-sealing rubber porthole in the Plexiglas cover by a remote control device.

crometer makes a calipering contact with the gage block and includes an automatic electronic fringe counter. No metallic contact with the specimen is made in the more traditional gage-block interferometer; measurement depends on the direct impingement of light rays, their displacement, and a slide-rule computation.

A contact type interferometer appears in Fig. 29. Such an instrument is, of course, mounted in a vibration-free manner. Its spherical contact, which has a large radius to reduce penetration error, is mounted in a gaging head that is raised and lowered by a slip-clutch motor drive. The operator brings the contact down to the anvil, and the digital counter is set to zero. He then raises the counterbalanced gage head and moves the specimen block into position. When the contact is again lowered, the gage-block size is read in interference bands or fringes and converted to millionths. The customary gaging pressure is about 1 ounce.

It is assumed here that the block has previously rested on the soak plate to stabilize its temperature and that everything has, of course, been thoroughly cleaned. At the moment of measurement the thermometer inside the gage is also read, as well as a barometer hanging near the gage. In addition, psychrometer readings for relative humidity are taken.

Generally, several measurements of the specimen block are taken either to try for repetition or to get an average. The final reading is adjusted — both plus and minus — by several correction factors, including those for temperature, humidity, and barometric pressure. Standard measuring conditions are: water vapor pressure, 7 mm Hg (or approximately 40 per cent relative humidity); atmospheric pressure, 760 mm or 29.92 inch Hg; temperature, 20 degrees C. or 68 degrees F.* Correction factors, methods of calculation, operating instructions, and other necessary data are, of course, supplied by the gage manufacturer.

A simple diagram of interferometer optics is seen in Fig. 30. Very briefly the system may be described as follows: A ray of light from the krypton tube is passed through a collimating lens to a beam splitter which breaks it into two components. One beam is directed toward a fixed prism reflector and the other to a prism connected to the measuring tip. The two beams then

* In rare cases, the carbon dioxide content of the air is analyzed and a correction is made for the standard condition of 0.03 per cent CO_2 by volume.

meet at a combining plate where an interference (dark band) is produced. This, in turn, is directed up to a photomultiplier tube. Impulses from the latter, together with the action of the cathode followers and the digital counter, effect the fringe counting.

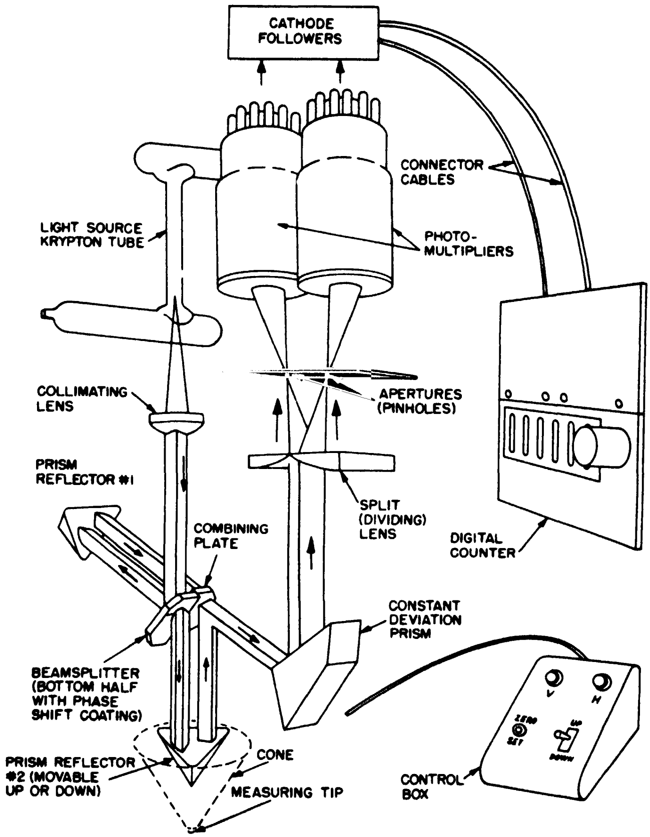


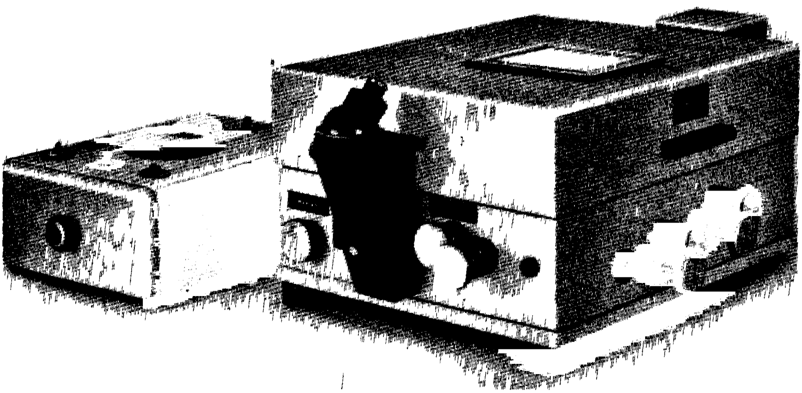
Fig. 30. A diagram which shows the operation of an interferometer.

Arrangements can also be made to add to or alter accessory parts of the fringe-count micrometer so that direct interferometric measurement can be made of strip stock, cylinders, and bearing balls, as well as gage blocks.

The traditional type of interferometer requires no metallic contact with the work-piece, but depends on light beams impinging on the gage-block surface. Hence, that surface must be smooth enough to reflect light without introducing a "change

of phase" error, the interferometer's equivalent of penetration. Also, all the rules previously given regarding the elimination of such error producers as dirt, vibration, and temperature apply to the *n*th degree if an interferometer is to give accurate results.

Until lately, interferometers have been strictly laboratory instruments used only by physicists and specialists. Now avail-



Courtesy of Carl Zeiss, Inc.

Fig. 31. A compact version of gage-block interferometer Three colors from a cadmium light source allow the measurement of a gage block by means of three scale readings and a special slide-rule calculation

able are compact models, Fig. 31, equipped with ingenious manipulating devices with which a competent inspector can secure quite accurate results. However, these still must be used in a temperature- and environment-controlled room.

While information on the construction and application of any such apparatus, as well as the theory behind it, should be obtained in detail from the manufacturer (including, at least, a capsule education in the principles of interferometric measurement), a rough description of the technique is appropriate here.

The hinged cover of the instrument shown in Fig. 31 can be swung up and open, disclosing a series of prisms, mirrors, a beam splitter, and other characteristic elements of an interferometer's optical system. These are all mounted on a solid metal base which, in a fashion, also acts as a soak plate or heat

sink. At about the middle of the beam path (under the glass window in the cover) is a card-size steel platform which can be made to move back and forth by means of exterior knobs.

A rectangular optical flat is placed endwise on this platform, at a scale designated location, and the specimen gage block is wrung to it. This setup is shown schematically in Fig. 32.

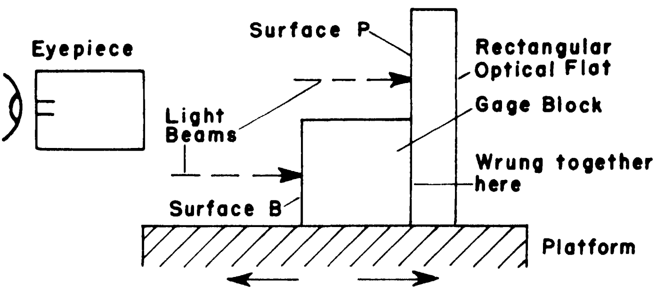


Fig. 32. Diagram of the setup employed in the interferometer which is shown in Fig. 31. The gage block is wrung to an optical flat placed vertically on a laterally movable platform. Light rays impinged on both the gage block and the optical flat produce the necessary fringe patterns.

In-phase and out-of-phase light beams from a cadmium source (housed in the box seen at the rear in Fig. 31) follow their standard interferometric paths. They impinge on the plano optical flat surface *P*, Fig. 32, and also on surface *B* of the gage block. The platform — optical flat — gage-block assembly is moved laterally until the inspector, looking through the eyepiece, sees sharp fringe patterns simultaneously at *B* and *P*.

What he sees may look like the pattern illustrated at A in Fig. 33, except that the fringes are colored. The instrument has controls so that the red cadmium light ray can be used, then the green, and finally the blue. The pattern seen at A, Fig. 33, would

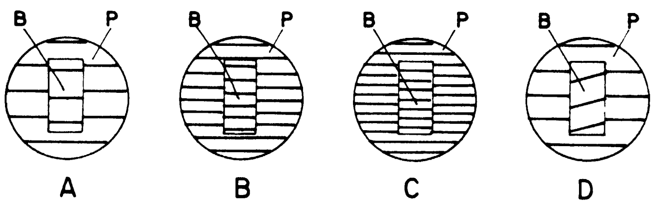


Fig. 33. Fringe patterns as seen through the interferometer eyepiece. Views (A), (B) and (C) illustrate three patterns that might be obtained in measuring a gage block with three wave lengths of cadmium light. The pattern seen at (D) is one which indicates that the gage-block face is not parallel to that of the optical flat.

be, say, from cadmium red; at B, from cadmium green; and at C from the blue rays. If for some reason the face of the gage block were not parallel to the optical flat (due to wear or lack of parallelism), the inspector might see a pattern more like that shown at D.

If, for example, the gage block were 1 inch in size and some arrangement were provided whereby the front surface could be moved gradually forward, the observer would see no fringes — just plain light — between each 0.00001267 inch of such movement, when using cadmium red light. After he had counted 78,900.4799 alternate fringes and light flashes he would know that the block surface had traversed a full inch.

Some such task would be arduous and time-consuming, and probably a counting error would creep in before all 79,000 odd fringes had been tallied, to say nothing of estimating a 0.4799 part of a fringe! Hence the use of the three colors of light and an ingenious scale device.

The fringe spacing for cadmium red is 12.67 millionths inch; for green, 10.02 millionths inch; and for blue, 9.45 millionths inch. This accounts for the differences in fringe spacing suggested by the sketches in Fig. 33. These differences plus an estimate of fringe fractions are employed in determining the length of the block. An exactly 1.000000-inch block would produce only one particular set of patterns and fringe fractions, like those seen in Views A, B, and C of Fig. 33. If the block were 1.000001 inch long, there would be a different set of patterns.

In addition to viewing the fringe patterns, the operator also sees in the eyepiece a ruler-like scale and a cross of hairlines superimposed on the fringes. In making a measurement, he makes a record of the scale readings, for all three colors of light. This information is then transferred to a slide-rule-like device from which the size of the block is calculated. After making the usual corrections for temperature, humidity, and barometer, the accurate size of the block under standard conditions is obtained.

Checking the absolute length of a gage block in an interferometer is somewhat time-consuming, not only in taking readings, but because a waiting period varying from twenty minutes to an hour or so is needed for temperature stabilization after the setup is ready for observation. The interferometer seen in Fig. 31 has two internal thermometers, each visible

through the cover window. One registers the temperature of the internal metal (soak plate) and the other, the internal air temperature. When the two thermometers read alike, an observation can be safely made.

One result of having access to an interferometer is a keener appreciation not only of a size difference of a millionth of an inch but also of how readily a several-millionths-inch error can escape unnoticed. Yet the prophecy is that it will be necessary before too long to be able to detect a size difference of 1/10 of a millionth of an inch with considerable confidence!

CHAPTER 16

Coordinate Measuring Machines

With the advent of numerically controlled machine tools, especially tape controlled milling and drilling machines, demand grew for a means to support this equipment with faster first-piece inspection and, in many cases, 100 per cent inspection. To fill this need, coordinate measuring machines were developed by modifying precision layout machines. Indeed, most coordinate measurement machines "double in brass" because they are used as layout machines before machining and for the checking of hole locations after machining. It has been said that the coordinate measuring machine is not just a refinement in gaging equipment but a major breakthrough in mechanizing the inspection process and in lowering its cost.

Breaking a Bottleneck with a Coordinate Measuring Machine

Let us take a specific example to see why an inspection department is prompted to install a coordinate measurement machine rather than rely on conventional surface-plate inspection methods. In this typical case a bottleneck develops when inspection is confronted with the necessity for measuring a dozen hole locations in fifty machined castings where 100 per cent inspection is required. The tolerances are plus or minus .001″ for location of the holes relative to their reference points on X and Y coordinates. The holes are also located in relation to an edge to very close tolerances. The inspector quite naturally turns to his surface plate, a precision knee, a stack of gage blocks, and a height gage. He mounts the casting on the knee on the surface plate and proceeds very much in the manner described in Chapter 7, Surface Plate Methods. Of course, he establishes a reference or starting point and, with the height gage and with various plug gages or wires in the holes, he proceeds to measure the hole center coordinates. Now because the basic surface plate technique is always perpendicular to or upward from the hori-

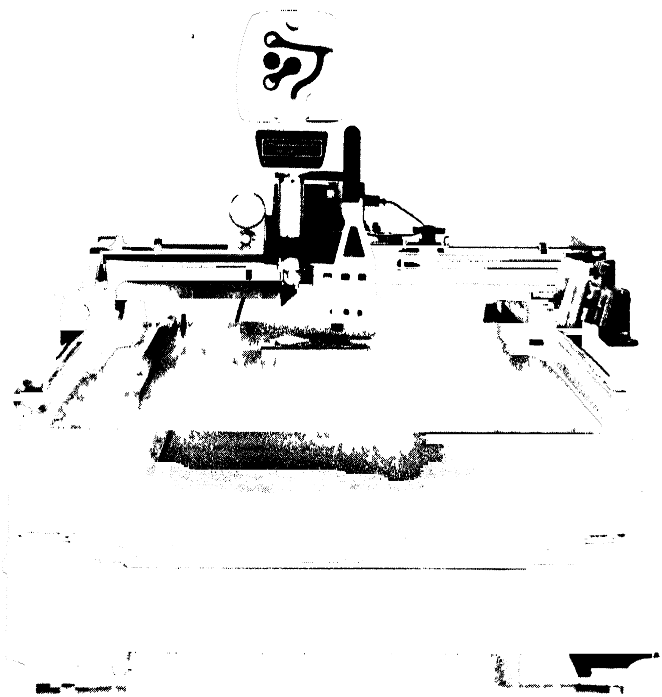
zontal plane of the surface plate, there must be one setup of the part to measure the locations of the holes in one direction (the X direction), and another setup to measure the locations of the holes in the Y direction (90 degrees from the X direction). The surface plate method is time consuming and tedious. Also to be taken into account is the possibility of errors in the gaging setup. The inaccuracies of the gage blocks, the height gage and indicator, the plug gages, and the precision knee must all be taken into account. The inspector too, has to be constantly on the alert in order to maintain accurate readings during 100 different setups on 50 pieces with 600 holes to be located and at least 1200 dimensions to check. The amount of time spent on the measurement of the hole locations in each of these castings might very well average two hours and the time spent measuring the batch of fifty parts would then be one hundred hours. No wonder the chief inspector looks for another faster solution to this problem!

Now let's take this same measurement job of 100 per cent inspection and instead of using conventional surface plate technique apply a coordinate measuring machine to the problem. To start with we'll use a mechanical coordinate measuring machine, that is, one that employs dial indicator readout rather than electronic meters. The casting is clamped to the measuring machine table in the same manner that it was held on the table of the drill. The coordinate measuring machine table is usually provided with T-slots or tapped holes or both for hold-down purposes. After the part is staged on the table, the tapered probe of the machine is inserted into each hole in turn, with the X and Y coordinates read directly from the continuous travel dial indicators. Both readings are obtained at each setting. The time to measure the locations of the 12 holes in both directions should not take more than 15 or 20 minutes including the time necessary to set the piece up on the table and establish the datum reference. In this case the probable time saved using the coordinate measuring machine as opposed to conventional inspection methods amounts to more than one and one half hours per part. What is demonstrated by this example is the prime advantage of the coordinate measuring machine which is quicker inspection coupled with accurate measurements. The coordinate measurement machine just described is a mechanical gage without electronics. This machine quite simply makes use of two-axis X and Y positioning tables to bring the work to the probe

that engages the holes to be inspected. A movable overarm permits adjustment over a vertical range of 12 inches while the vertical probe movement in any one setup is 4½ inches. The capacity of the machine is 12 inches on the X axis and 10 inches on the Y axis with positioning accuracy claimed to be ±.0005 inch.

A Coordinate Machine with Optical Comparator

Another mechanical coordinate measuring machine, Fig. 1, is equipped with an optical comparator as well as travel dial indicators. A machine such as this one can be used to check a



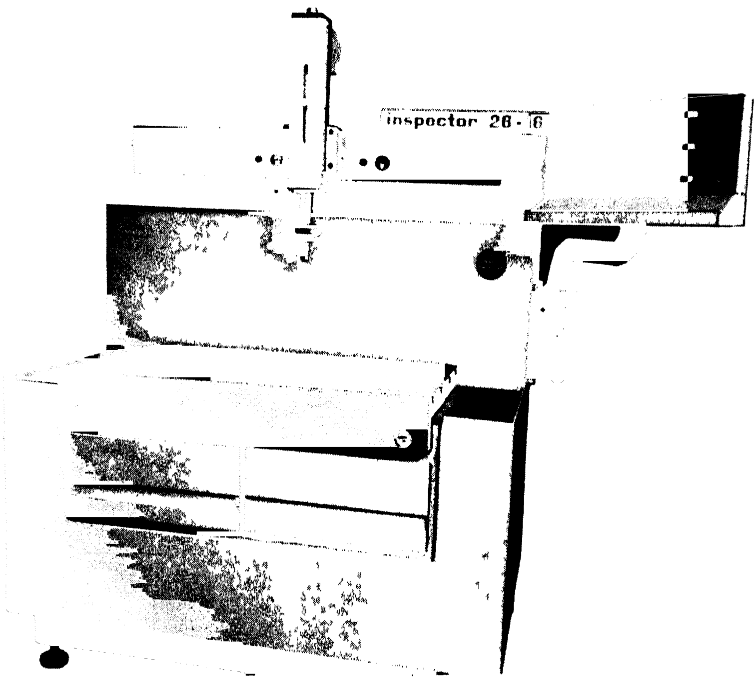
Courtesy of OPTOmechanisms Inc

Fig. 1. A mechanical coordinate measuring machine equipped with an optical comparator and travel dial indicators.

wide variety of components and is especially adapted to the checking of hole locations in flat plates, and printed circuit boards. The machine is accurate to ±.001 inch yet capable of the rapid inspection so necessary when over 500 holes must be verified in one piece.

Electronic Measurement and Digital Readout

Just as we have seen continual improvement in other areas of dimensional measurement there has been constant development of new and better coordinate measuring machines to keep pace with the space age technology of close tolerances, zero defects, and numerically controlled machine tools. Measuring machines with greater accuracy and precision combined with larger capacity and high speed operation are being designed and built. Figure 2 shows a typical three-axis machine, *X*, *Y*, and *Z* coordinates with accuracy said to be ±.0005 inch and



Courtesy of Farrand Controls, Inc

Fig. 2. A typical three-axis, digital readout coordinate measuring machine. This one uses a measuring element called Inductosyn.

resolution of .0002 inch over all three axes. Measurement is accomplished by electronic means without lead screws and with digital readout. The measuring element is called the Inductosyn data element and uses inductive coupling between conductors separated by a small air gap. Linear accuracy in the order of 50 microinches is claimed by the manufacturer. The element

is not subject to wear and so will not become inaccurate, and is impervious to oil, dust and other contaminates. The digital readout has automatic plus and minus indication from a zero reference. The readout is in 5 or 6 digits plus a meter indication.

The work-piece can be aligned quickly with the probe by the means of a swiveling adjustment on the work-table. The operation of this machine is fast and easy for the inspector who has fingertip control of the measuring probe for movement over all three axes X, Y, and Z of the part being checked. Furthermore, there is no need for reference standards such as gage blocks, templates, or other external devices.

The Moiré Fringe Concept

The digital measuring system used on the coordinate measuring machine pictured in Fig. 3 is unique because it is based on

Courtesy of Sheffield

Fig. 3. The measuring probe of an XYZ coordinate measuring machine is inserted in a hole in a casting which is staged on precision parallels clamped to the machine table.

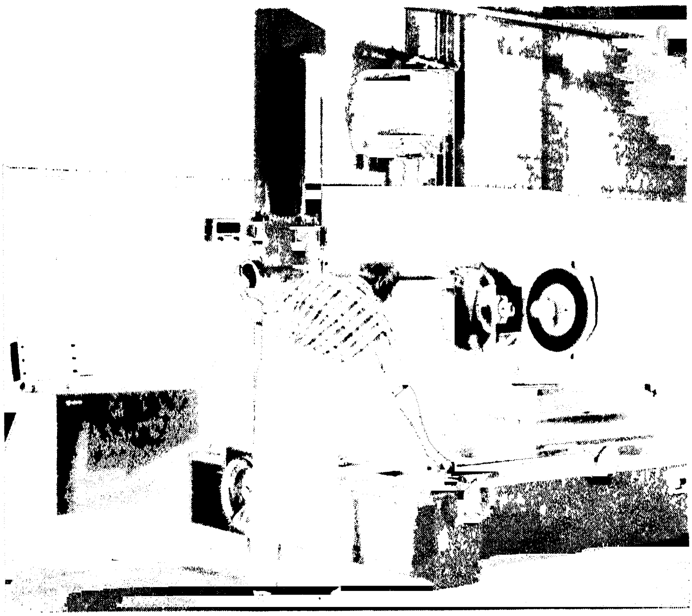
the Moiré fringe concept of measurement. The main element of the system is an accurately ruled grating of the necessary

length. An index grating with the same line structure is superimposed to produce a pattern of dark and light bands. This integrated interference pattern is a Moiré fringe — a greatly magnified replica of the line structure. The light intensity is converted into electrical signals by four photo cells and the outputs from the photo cells are used to produce a digital display equal to the motion. Signals from the photo cells will also give an indication of direction and the digital display instantly follows any change in the slide movement. Although the two gratings are superimposed, they do not touch and continual use will not cause wear. In operation, the work-piece is mounted securely to the table, just as it was in the earlier examples, using appropriate bolts, clamps, and blocks. The part is aligned with the probe travel by adjusting the table aligning device. With the proper tapered or flat tip in place, the probe is moved to the first point of check or reference position and both coordinate readouts are set to zero by pressing the X and Y axis buttons. The probe is then moved in turn to the various points of inspection with the X and Y coordinate dimensions being displayed simultaneously at each inspection point. Somewhat the same procedure is used when using the vertical or Z axis accessory. The probe movements, in this case, are measured by a four-pickup counting head as it travels over the steel grating which has one thousand lines per inch. The corresponding grating segment mounted on the counting head creates a Moiré fringe pattern as it passes over the grating. As the fringe patterns are counted, output signals from the head provide a continuous readout of probe movement and position. Machines such as pictured in Fig. 3 can be obtained in several sizes. The smallest are bench mounted and are suitable for measuring small parts such circuit boards. The larger models have more measuring range and work height capacity with the largest size designed for the measurement of heavy parts such as engine blocks and big machined castings and forgings.

More Speed with Electronics

Coordinate measuring machines of more sophisticated design with many special features and optional accessories which speed up the inspection (or layout) process are being built. The basic gaging principle is always similar to the previously shown example where a mechanical measuring machine with travel dial indicator readout was used to make a 100 per cent check on a

batch of fifty drilled castings with considerable time saved over conventional gaging methods. With more elaborate electronic equipment, not only is greater accuracy obtained but also greater speed — up to twenty times faster than with the old reliable surface plate technique. Some of the accessories available are: an optical viewing screen or optical comparator attachment as shown in Fig. 1, a microscope attachment for the inspection of thin, soft, or delicate work-pieces, and automatic printout as shown in Fig. 5 which eliminates the inspector's pad and pencil.

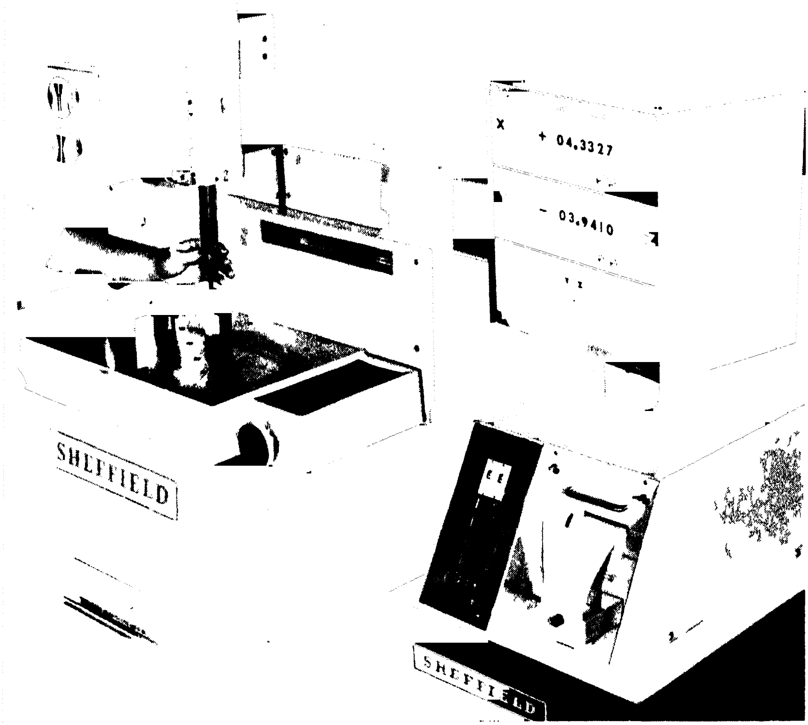


Courtesy of Portage Double Quick Inc

Fig. 4. A coordinate measuring machine built to handle large work-pieces and with added features which make the machine, in effect, a universal measuring machine

Accessories for Combined Measurements

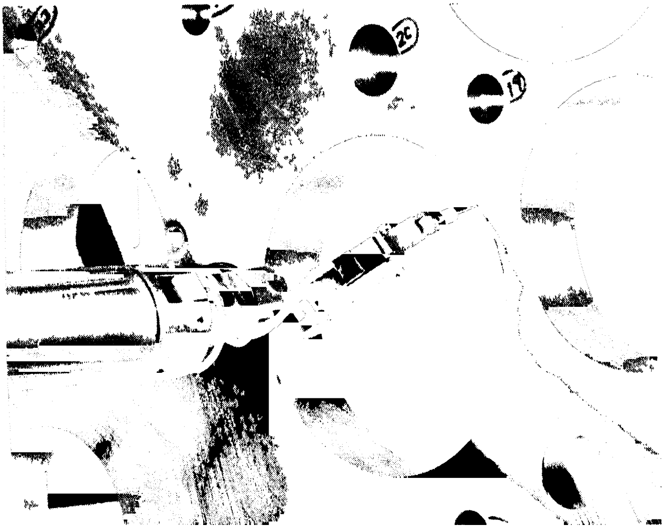
The versatility that can be built into a coordinate measuring machine is shown in Fig. 4. Here is a machine which is not only equipped for three-axis coordinate measurement with digital readout but is also designed to permit the checking of angularity, roundness, taper, and concentricity. This machine has an electronic measuring system accurate to $\pm.0002$ inch and repeatability in the order of .00015 inch. A feature which makes



Courtesy of Sheffield

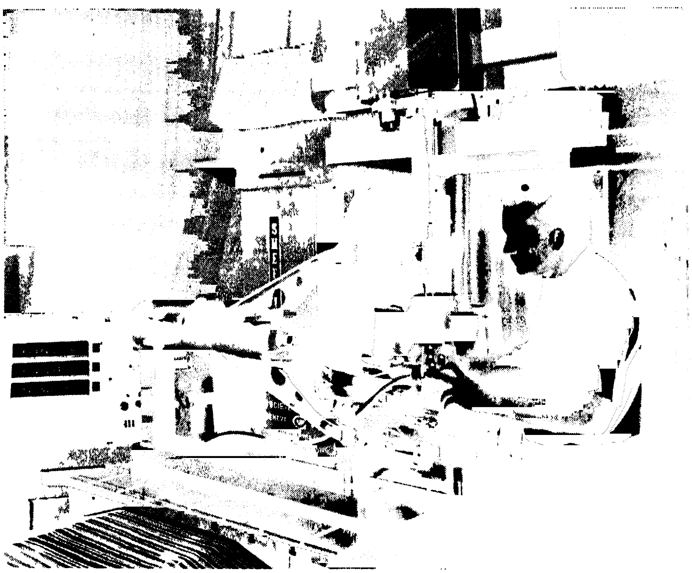
Fig. 5. A coordinate measuring machine with automatic printout as well as digital display of the measurements

the machine so versatile is the rotary table for reaching other areas of the part being checked without changing the setup, thus eliminating possible error which could occur in multiple setups. There is also an electronic indicator probe which is mounted on the end of the spindle, Fig. 6, which can reach over and under the work-piece to check squareness in a single setup. Designed for heavy part inspection and layout, as can be seen in Fig. 4, the machine has a main base of granite 18 × 46 × 70 inches. Another measuring machine which is more than just a coordinate measuring machine is shown in Fig. 7. This machine makes use of linear air bearings on the horizontal slide motions to achieve finer slide position resolution. In addition to a printer or typewriter, readout devices such as paper tape punch, magnetic tape, card punch, and outputs for post processing can be provided.



Courtesy of Portage Double Quick Inc

Fig. 6. A closeup of the electronic indicator probe mounted on the end of the spindle of the coordinate measurement machine illustrated in Fig. 4.

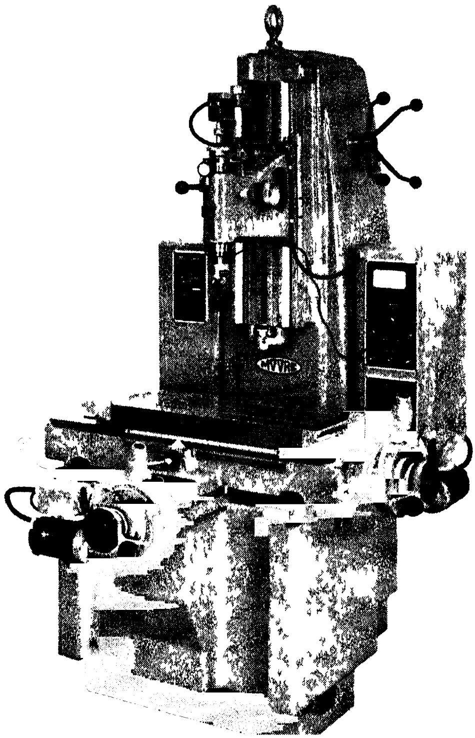


Courtesy of Sheffield

Fig. 7. A universal three-axis measuring machine with bridge type construction. This machine has linear air bearings for the horizontal slide motions.

When Masters are to be Measured

When the tolerances are in tenths of thousandths, such as in the case of precision masters, probably the most reliable method for accurately measuring hole locations is with a very precise universal measuring machine of the type illustrated in Fig. 8. This universal measuring machine has been described as the



Courtesy of Moore Special Tool Co

Fig 8 This universal measuring machine is especially suitable for the checking out of special masters Accuracy of the spindle is 5 millionths of an inch and the machine is accurate to 35 millionths of an inch on the X and Y axes

"ultimate in coordinate measuring" and it is hard to disagree with that assessment, although toolmakers' microscopes and optical gaging equipment of various sorts are now available which can be used with confidence to check to .0001 inch (see Chapter 11, Optical Measurement and Inspection Equipment). The universal measuring machine is built along the same lines

as a jig borer or jig grinder. Indeed, if such a measuring machine is not available, a jig grinder can be a very useful substitute if the tolerances will allow it. The accuracy claims for the universal measuring machine shown in Fig. 8 are 35 millionths of an inch tolerance on the X axis and 35 millionths of an inch tolerance on the Y axis with spindle rotation accuracy of 5 millionths of an inch T. I. R. Where would one expect to find a machine like this and who would operate it? Well, certainly not the average mechanical inspector in a machine shop. The universal measuring machine should be located in a temperature controlled room or measurement laboratory. The machine is not normally used for ordinary production piece parts but is especially adapted to the checking of precision masters and very accurately machined special parts. The universal measuring machine is virtually a complete metrology laboratory in itself and can be used for measuring coordinate dimensions on small and large parts as well as other geometry of the part such as contour, taper, radii, roundness, squareness, and many other measurement tasks. For coordinate measurements, a piece is staged on the machine table and the reference datum, an edge or hole, is indicated out to zero using a high magnification electronic indicator built into the machine. Where applicable, the work-piece is squared up or leveled; then, using the leadscrews of the machine, the table is moved and the hole to be checked is indicated out to zero with the actual readings in X and Y axis being read on the verniers of the machine. When checking very close tolerances in "tenths" or fractions of a "tenth," the part must be brought to the same temperature as the measuring machine, preferably 68 degrees F.

Possible Sources of Error in Coordinate Inspection

The inspector must always remember that the table and the probes of coordinate measurement machines are not in perfect alignment nor will they always have perfect geometric form. The probes will have a degree of runout so it is advisable to locate a probe at the same rotational position; otherwise a "tenth" or two will be lost in extra tolerance — maybe even several tenths. Also, those probes that move up and down in the Z axis are liable to have some perpendicularity error. Speaking of perpendicularity, it is essential that the inspector always get the primary datum reference surface of the part square to the machine probe. There is also the possibility of error in the opti-

cal readout of a digital system. The inspector should calibrate these machines before using them wherever possible. Some machines have a master plate to use as a master calibrator but in every case a master of known hole spacing should be available so that each coordinate measurement machine can be calibrated. Care should be taken not to try to get exact measurements from a coordinate measuring machine when the last digit in the digital readout is blinking between two adjacent values. Finally, the inspector would do well to have a thorough understanding of the operating instructions included with the coordinate measuring machine and should know the specified accuracies of the machine, both mechanical and electrical.

CHAPTER 17

100 Per Cent Inspections

There are occasions in industry where all the pieces, components or units must be inspected and the defective, substandard, mismated or wrong size or model culled out. In contrast to the sampling procedures which are customary in patrol inspections, checks and tests and to statistical quality control techniques, the type of inspection which requires examination, test, measurement or observation of every unit is called 100 per cent inspection. *Detailing, screening, sorting* are more or less synonymous terms for the same operation.

A Wide Variety of 100 Per Cent Inspections

Such inspections may be only visual inspections. Or they may involve only gaging. Many times both operations are combined. 100 per cent inspections cover all types of testing — electrical tests, hardness tests, spray tests, trial runs, tests for noise and vibration, accuracy tests and a legion of others.

The type of test or inspection may be purely functional. In such a test the product is actually used, run, worked, at inspection, in about the same manner the customer will use it or it will be tested in the way it will enter an assembly. Running a ring thread gage over a screw is essentially a functional test although screwing on the actual nut which will eventually assemble to the screw would be the ultimate and purely functional inspection of the screw.

Many inspections are semi-functional. A number of gaging operations fall into this class, the gage taking the place of the mating part. The final factory test on a vacuum cleaner includes wattmeter readings and a dielectric test to ground, plus coupling a vacuum gage to it, these tests do not simulate actual working conditions but indicate, from previous engineering laboratory experiments, that the cleaner will do the work expected of it without breakdown or shock hazard.

A hardness test will indicate whether or not a heat treated shaft, for example, will withstand wear from friction or abrasion because there is a definite relation between the hardness of steel and its resistance to wear.

Many inspections and gagings are made to prevent waste, scrap and lost time at subsequent operations or assemblies. If a shaft is rough turned to too large a diameter, the following grinding operation will require too much time for taking off unnecessary metal. If the shaft is rough turned too small, it is scrap; the grinding wheel does not put on metal.

In this section various kinds of 100 per cent inspection operations are being described separately. Strictly manual operations like gaging, for instance, are taken up by themselves and then visual inspections are discussed. Automatic gaging and sorting and a variety of special tests are also described. By considering these operations separately, the principles involved can be more readily made clear. But it must be remembered that in industry, the operations are seldom so broken down; an inspection is usually a combination of tests, observations and measurements.

Historically, 100 per cent inspections probably started with the complete observation, test and functioning of each unit of the product just before it was packed for shipping, a shop routine usually named final inspection. Then 100 per cent inspections moved back into and through the shop to the several locations where detailing or screening seemed necessary. The final step was to subject purchased components and materials to 100 per cent inspection.

Manual Inspections

The first step in manual inspection is practical preparation. The setup for an inspection is just as important, from the point of view of efficiency, as the preparation for a machining operation. The principles of work simplification* find an immediate application in most 100 per cent inspection work. The object of the inspection operation is, perhaps, to check a certain diameter on a series of workpieces. The actual final adjustment of the piece on the gage anvil plus the flick of the indicator hand may mean only a matter of a second, but

* Any inspector who can arrange to attend a course in modern work simplification will find he has added a worthwhile industrial asset.

getting the piece to the gage and *away* from the gage is frequently another matter. In work simplification terms, the "make ready" and the "put away" might consume from ten to twenty times the amount of time and energy used for the "do."

Properly Versus Improperly Arranged Work

A simple diagram, as in Fig. 1, illustrates a common error. Suppose the work is to lay on or in the gage as shown at *a*. Usually the rod-like workpieces would be piled on the bench neatly enough perhaps and accessible, but in the direction

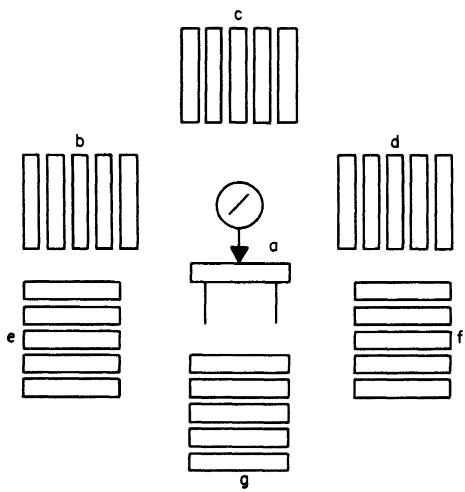


Fig. 1. Possible work-piece arrangements relative to the gaging device which may be used in 100 per cent inspection procedure. Positions *b*, *c*, and *d* require extraneous hand motions. Positions *e*, *f*, and *g* reduce the work motions.

shown at *b*. Too many times they are piled over in back of the gage as at *c*. The inspector not only reaches for each piece but he must turn it, juggle it, to get it around into the *a* gaging position. Then just as frequently he deliberately turns it 90 degrees again so that it will pile neatly at *d*.

Suppose the work were piled as diagrammed at *e*, and repiled after gaging as at *f*. Several arm and wrist motions have been eliminated because the work can be slid straight across the gage. The work motions have been streamlined. Perhaps it would be easier to have the "put away" at position *g* so that the instant the indicator registered the measurement,

the workpiece might literally roll off on to pile *g*. The arrangement shown in Fig. 2 is an example of good planning. Attention to such details saves a lot of human energy.

Somehow inspectors seem to "cross hand" themselves. They persist in removing each piece from the gage with the right hand and reach over across the left hand to dispose of it. Or they reach to the floor with the left hand for the work, gage

Fig. 2. An example of how a good handling set-up reduces the expenditure of energy in moving a work-piece to and from the gage.

it, and again reach to the floor on the right to dispose of it. If inspection work were a matter of gymnastics or slimming exercises, many operations would be complete successes.

Concentrate on the Act of Measurement

The trick in manual inspection is to concentrate all the attention and energy possible on the measuring act itself and as little as possible on all else. Unnecessary hand, arm and body motions distract; they take energy, time and attention which are better devoted to the work place. The more automatic the necessary gaging motions become, the better inspection job will be done. The inspector should never reach an inch farther or higher than necessary in order to pick up the parts he is gaging nor reach over or down in order to dispose of them. Attention to such details can convert a wearisome, even ex-

hausting, day into an easier task and in addition save many minutes of time.

The expert typist or pianist is observed to be free of unnecessary extra physical motions. He never watches his fingers. In fact, from practice, he is unconscious of them and concentrates solely on the notes and composition. And he never sits in an awkward, strained position.

The position of the gage is likewise essential of course. If it is too near or too far back on the bench, too high or too low, aching shoulders may be the penalty after an hour or so of inspection. The indicator should be at natural eye level. If possible, perform manual inspections while seated in a chair of the proper height.

It is also desirable to locate manual inspections so that the inspector is not directly facing the glare of windows or unshaded lights. The same general sort of psychology applies in attempting to avoid a work area beset with the continuous vibration and thump of machinery or where the ventilation is poor. To perform manual inspections near employees who talk and chatter all day like magpies is extremely and unnecessarily tiring. Remember that, at best, repetitive manual inspections are monotonous; it takes enough of a particular kind of stamina to withstand the boredom anyway without adding unnecessary nerve strain.

Use Two Hands for the Workpieces

Where hand gages are used, such as micrometers, snap gages, depth gages and the like, the tendency is to hold the gage in one hand and pick up the pieces to be measured with the other. One hand, then, is acting simply as a vise. It is almost always possible to secure or devise simple clamp stands to hold the gages. Then both hands are free. Some shops equip gages with foot pedal devices for opening and shutting the jaws.

The inspector should train himself to pick up the pieces with one hand and apply them to the gage. In the meantime the other hand is either picking up the next piece or disposing of the last one. Good manual inspection displays rhythmic, alternate come-and-go motions of the hands.

In addition to efficiency gained, there is another good reason for having a gage clamped in some sort of stand. Where a gage is held continually, the heat from the hand is transmitted

to it and as a result of internal expansion the measurements may become inaccurate.

Most inspection and gaging apparatus is designed to readily accept the piece, part or component in the correct manner. The inspector should avoid twisting, cramping or misaligning the work in the gage. This means he must have been first well instructed in the use of the gage. Secondly, he should relax; let the gage do its own work.

Avoid Three Types of Errors

At manual inspections three common types of errors should be avoided. The first, *parallax*, as has been previously mentioned is due to reading a scale or dial at an angle so that the reading seems to be higher or lower than it actually is. Position the gage directly before the eyes.

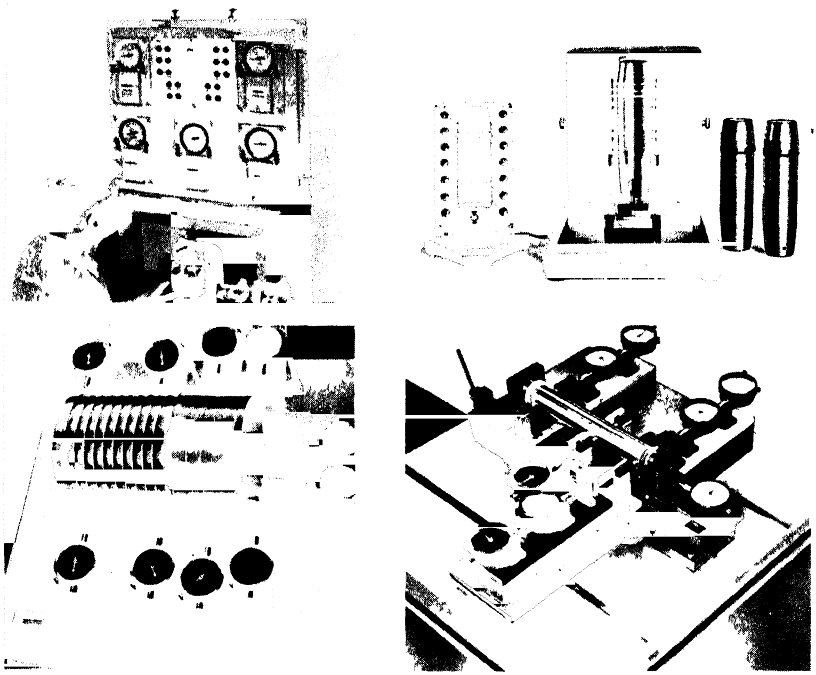
The second common mistake is known as *rounding off*. For instance, the reading for a diameter might land between .758 inch and .759 inch. The inspector would read, say, .758 inch. In individual cases, the error might be trivial or harmless, but in repetitive inspections, especially where precision is required, rounding off can lead to unjust rejections or to the acceptance of substandard work. The answer to rounding off is to secure gaging equipment with the required discrimination.

Another error is caused by what is called *flinching*. It is the deliberate practice of giving the product the benefit of a doubtful reading. If in the example above, the .759 inch reading would bring the part within specifications, some inspectors would decide on the .759 inch. Or vice versa. Both rounding off and flinching are slack traits which unfortunately tend to grow worse until the habit becomes so fixed that practically all of the inspector's readings are undependable.

Use of Multiple Gages

In modern factories, attempts are made to reduce much of the effort and time used up in 100 per cent manual inspection operations by the adoption of multiple gages, which are illustrated in Fig. 3. Multiple gages are made which register simultaneously anywhere from two to a dozen dimensions at once. At first thought, the inspector would seem to be thrown into a quandary as to how to read correctly several dials staring at him from all angles.

For the first few pieces gaged, his eyes *do* travel around the circuit of indicators as they did when he mastered the



Courtesy of Sheffield
Courtesy of Colt Industries, Pratt & Whitney Machine Tool Div
Courtesy of Federal Products Corp

Fig. 3. The use of multiple gages that measure several dimensions simultaneously reduces the number of handling operations required for complete inspection of a work-piece.

gage originally. Usually when the gage is mastered, gage adjustments can be and are made at each station so that each indicator registers the correct basic dimension and each indicator hand is pointing in the same direction. As the workpieces are placed in the gage, the indicator hands then take different positions, since few workpieces ever duplicate the master dimensionally. However, the inspector soon gets used to the indicator dial sectors within which the indicator pointers would ordinarily come to rest when the workpiece dimensions are within tolerance. In fact his eyes become so accustomed to the appearance of the gage's indicators with in-tolerance pieces that they immediately and readily register any indicator reading falling outside the normal dial sectors. Frequently the indicators are equipped with so-called tolerance hands or masks. So long as the indicator hands flick inside the toler-

ance hands, no impression reaches the attention of the experienced inspector. But where a reading shows outside the tolerance sector, his eye and consciousness immediately register the discrepancy in the overall appearance of the gage.

In recent gage designs, electric lights or bull's-eyes have been added. Figure 3 shows two examples of this sort of equipment. When the gage itself registers any one, or several, dimensions as out-of-tolerance a bull's-eye lights up, usually a red light. The human eye, of course, detects a lighted bull's-eye with several times the celerity and ease it can the position of an indicator or meter needle. On some designs, the refinement is added of having an amber light signal undersize, a red light oversize and either no light or a green light for correct size. (It is equipment of this type to which bells or buzzer tones can be added to direct a blind person employed at manual inspection.)

There are many occasions where manual inspection seems better performed where the inspector is standing. The weight and sizes of the workpieces may preclude sitting down. In general, if the workpiece is considerably heavier than the gage, it is easier of course to bring the gage to the work than the reverse. The work may be travelling along on a conveyor or for production reasons it may be lined up on a bench. But, unless the manual inspection job is temporary or intermittent, it is far better to rearrange the mechanics of the situation, somehow, so that the inspector can be sitting. Anything that tires an inspector unnecessarily, like continuous standing in one place, only drains away from the energy, concentration, dexterity and accuracy he requires for performing the consecutive measurements he is expected to make. Chutes, belt conveyors, high stools or similar aids surely can be planned for the inspector who is to detail work all day long.

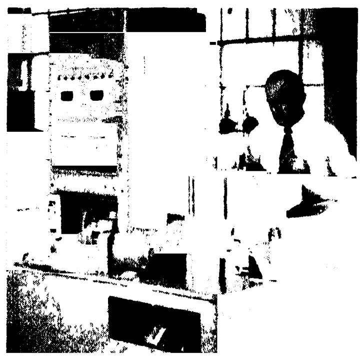
Automatic Gaging

It is natural to think of mechanizing manual inspection, of having the pieces and the measuring act itself all automatically handled by machinery. This subject has been fairly completely covered in the foregoing Chapters 9 and 10. As has been previously intimated, there is available and in contemporary use a wide variety of automatic, 100 per cent gaging machines, so much so that only a few hints of the extent of designs in use can be offered in this space.

In many cases the parts and workpieces which are to be 100 per cent gaged are fed to and into the gaging equipment on belt conveyors, chutes and other materials handling apparatus. In other situations the gage is hopper fed. Such a sorting machine appears in Fig. 4 where, as can be seen, small parts are being poured into the hopper. They will be automatically gaged and sorted into good and bad classifications as well as into size classifications.

On many occasions a 100 per cent visual inspection is required as well as a 100 per cent gaging for certain characteristics. Under such conditions it is often economical to have the inspector simultaneously inspect the parts visually (discarding any rejects) and feed or load the gaging machine. Such an operation is illustrated in Fig. 5.

The interesting feature of such equipment, in addition to the mechanical ingenuity displayed in designing the motion mech-



Courtesy of Federal Products, Inc.

Fig. 4. (Left) A hopper-fed gaging machine that automatically measures and sorts batches of small parts. Fig. 5. (Right) Combining 100 per cent visual inspection with automatic gaging.

anisms that imitate human hands, is the so-called electronic memory circuit which registers a measurement and holds that registration long enough to operate the correct switch when the piece gets to the disposal chute even though, in the meantime, another piece is in the line registering its measurement.

Automatic equipment can be designed to cover a wide variety of measurements. Figure 6 shows a gaging machine for measuring bearing balls and classifying them, automatically, into several size grades for later selective assembly purposes.

Courtesy of Federal Products Corp

Fig. 6. Automatic gaging machine which measures and classifies ball bearings for later selective assembly purposes.

Keeping the Automatic Gage in Good Working Order

Where the inspector has some responsibility in connection with such type equipment there are one or two fundamentals he should keep in mind. The first is not to presume more mechanical knowledge and ingenuity than he actually possesses. There is always a temptation to tinker with an automatic gage. The warning just given applies with even more emphasis to the electric and electronic sections of such gages. Probably nothing would suit the radio ham more than to trace out the "circuit" in one of these machines and fiddle with tubes, condensers, resistors and relays. Repairs, adjustments and electrical corrections probably will need to be made, but the best man to do it is one who has had thorough instruction and coaching from the equipment manufacturer.

Instructions for adjusting the gaging mechanisms so that correct measurements are made and maintained should come also from the manufacturer. This part of any automatic gage is no different than any other type of gage. It must be "mastered"; it should be checked for repetition; and if the gage is

more than a simple comparator, it may need to be recalibrated at suitable intervals. Freedom from dirt, grit, oil, nicks, dents and corrosion are just as essential on automatic equipment as on bench or hand gages. An automatic gage should be located as much as possible away from vibration, drafts, radiators or direct sunlight.

As a routine, perhaps hourly or perhaps less often, samples of the workpieces sorted by the automatic gage should be carefully checked with accurate portable or bench gages. Check not only the passed work but also some rejected pieces to be sure the equipment is sorting properly within specified tolerance bands.

Since most automatic equipment relies on electricity or air, or both, for its gaging operations, the line voltage and the air supply pressure should be regularly checked.

Visual Inspection

One of the more common 100 per cent inspection operations is the examination of finished products, parts, components and materials for visual defects. Appearance is important as well as function and various degrees of mechanical perfection. The rule applies to automobiles or wrist watches, to carving knives or rubber boots. Wire and cable in reels, paper on rolls, cloth in bolts, rubber, plastics, asbestos, table salt or packages of cigarettes, all must have a certain eye appeal.

Visual inspections, however, are used also to detect mechanical deficiencies as well as lack of merchandising appearance. A burr on a press part may prevent ready assembly; a blow hole in a casting is not only unsightly but it very often weakens the piece structurally. Neither are readily measurable in the sense, say, of gaging a length, outside diameter or thickness. The color of brass forgings can indicate whether the brass is too hard and brittle. Bubbles and waviness in blown glass distort the television picture. And how can the strength, security, completeness of soldered electrical connections (look inside your radio set) be quickly measured better than by an experienced eye?

It is impossible in a book of this size to name or describe more than a very few examples of visual inspections. However, the fundamentals and principles connected with the mechanics of routine, repetitive visual inspection apply practically throughout.

Knowing What to Look For

The first thought of anyone about to start a visual 100 per cent inspection should be about what to look for. The conditions, the appearances, the items or elements governing rejection or acceptance of materials, parts or products — the standards in other words — are established in industry by the engineering department, the laboratory, by the sales or service departments, frequently by the chief inspector or quality manager, occasionally by the manufacturing departments and sometimes out of sheer necessity by the inspector himself.

It might be well for the reader to stop here long enough to review Chapters 2 and 4.

As a prerequisite for expert visual inspection, an inspector does well to secure, somehow, time enough to become acquainted pretty thoroughly with the manufacturing process through which the goods he is inspecting are routed. To know more or less exactly what causes the sort of visual defectiveness he is supposed to look for is a big help. His study should probably go back of the operations immediately preceding the inspection for underlying causes and conditions. The final trouble may start from the condition of materials and parts coming in the receiving door. Scratches, pits, scale and tarnish on silverware pieces can be traced many times to the original sheet stock; slubs, snarls, knots and ravelled yarn in high price worsted suitings originate mostly at the cards and spinning frames. In a paper mill, road tar that was accidentally splashed on lengths of pulp wood, for example, could well show up as spots on the finished pages of this book. A worn bearing in a milling machine can mean unsightly chatter marks on a machine part.

In a similar manner, the inspector should know where the parts or materials he inspects are going. If he is inspecting the interiors of tire valve bodies for cracked and split fiber washers, he will appreciate the reason for his inspection work more after he has suffered from a slow leak and a flat tire on his car. A period of work as an assembly operator helps. Salesmen make meticulous inspectors because they have so many times faced the complaints of irate customers over substandard and shoddy merchandise. The inspector in the woodworking shop soon learns what to look for after he has worked in the paint shop.

To establish some of the basic principles and techniques of

100 per cent visual inspection, let us use as an example some small, simple metal ferrules shaped something like, say, fountain pen caps. We could consider any similar sized machine or plastic parts for the purpose. Or gaskets, glass marbles, paring knives, playing cards, bronze bearings, ad infinitum.

The assumption is made, too, in this discussion, that the inspector is occupied almost entirely every day with repetitive work of this nature.

Preparation for Visual Inspection

The first step in preparing for a 100 per cent visual inspection task has already been suggested. Be sure that the extraneous physical circumstances surrounding the job have been made as comfortable as possible. Chair, bench or table should be of the right height. Light should be adequate with no direct glare. The inspector should not be facing extraneous light as, for instance, a row of windows over beyond his work place. The remarks about vibration, noise, neighboring human chatter and poor ventilation already brought up in the discussion of manual inspection apply here also, of course. Freedom from drafts and other forms of personal discomfort is essential. Visual inspections ought to be located away from through aisles if possible. The intermittent rumbling of hand trucks and shop tractors going by is distracting; also the personal interruptions of passersby.

Work simplification principles apply. The actual visual inspection per piece may be executed in a flash. It is a pity to waste energy and time needlessly fumbling for parts, getting them before the eyes and transferring them to the "good" box or on to "reject" tills.

Remember that basically only the eyes are needed to do the work of visual inspection. Try to eliminate everything and anything that delays or distracts them. Remember too that, also basically, there are as many decisions to be made as there are pieces in the lot being inspected. If the inspection is proceeding at the rate of 1,000 pieces per hour, 1,000 decisions per hour are made. As each piece passes before the eyes a decision is made that it is acceptable or rejectable.

Assuming that adequate forethought has been given to reducing general physical discomfort and strain to a minimum, several practical steps can be taken to lower eye strain and nerve tension. The trick in continuous, repetitive visual inspec-

tion, strange as it may sound, is never to see, almost literally, the good work — never to be conscious of it.

The story is told of the trapper back in the days of Indian warfare who came to his cabin door at daylight and surveyed his little clearing. His glance ranged back and forth over the fringe of the forest. The story spoke of the infinity of detail that met his eyes — all the twigs, leaves, tree trunks, blades of grass, stones, patches of moss and every flower, berry or fern. Yet, the story said, he didn't see a thing! But — had there been a branch broken, a leaf falling, a blade of grass tramped down or a stone kicked out of place, his eyes would have detected it instantly, for his life depended on such vigilance.

An inspector must learn the trapper's habit of instantly seeing the unusual, that which is not as it should be. We all have that knack to some degree. At the theater many of us will observe the mantle clock chiming four in the afternoon when obviously, according to the plot, it is ten in the morning and any of us will ridicule the 1950 model car used by gangsters in a 1920 bank robbery scene.

Utilizing the Screening System for Training

To make the principle of screening implied above practical, an inspector is urged to secure a quantity — several hundred to a thousand pieces — of the type of part being inspected (ferrules in our example) which have been carefully preselected as being satisfactory. Each piece need not be perfect, any one could contain a degree of defectiveness, (a few can be borderline) but they must all be commercially acceptable under existing standards, the kind that would normally go in the "good" box.

The inspector then goes through the motions of the routine inspection, handling and examining each piece. Having thus gone through the batch once, he should go through it again, this time probably picking up manual speed. Repeat the inspection operation, with all conscientiousness, several times until the eyes, the mind, the consciousness, are thoroughly accustomed to good work.

Then select a ferrule that is defective, one with a rather obvious defect about it, and bury it in the box of good work. As you start to inspect again you will find yourself tensing (especially if you are new to inspection or if the particular inspection is new to you) the way a golfer will almost inevi-

tably tighten up on the first tee. Relax. Get into the mechanical rhythm of the inspection. Remember the trapper. Remember your eyes are thoroughly accustomed to the appearance of good work. You will find to your surprise that you hardly need concentrate; the defective ferrule, when you come to it, will almost jump out at you.

Experienced inspectors who feel they have gone stale at their work are urged to rehearse a few times on a batch of strictly good work and then inspect out a couple of defectives deliberately buried in it, as above.

The screen system just described forms an excellent way of training green inspectors or, for that matter, educating experienced inspectors on new products, new types of defects or changes in standards.

The Wrong Way to Train a New Inspector

This is the way the new inspector is shown how to do the job in the average factory. The employment office may tell her a couple of generalities about inspection work. The chief inspector, with a few sample parts in his hand, then starts dutifully to teach her the art of inspection. But he soon tires, or his 'phone rings, so he calls in his inspection foreman. The latter is wiser; he beckons to Gertrude the experienced inspector and orders her to break in the new girl.

Gertrude scrambles around and hunts out some defective ferrules. She points to one type of nick and tells the new girl she must look for that sort of thing. She holds up a ferrule with a bent lip. Number three type of defect is an oil spot; number four piece discloses a fold or wrinkle. And so on. There are twenty-eight different types of defects the new girl must know. But quick — Gertrude is losing her piece rate.

By the time the green inspector has concentrated on the fourth type of defect her mind has begun to refuse any more information. Three more types of defects and utter confusion prevails. It would be much easier to take a box of good work, let the operator get used to it and then introduce the several types of defects, one or two examples at a time, while the neophyte is learning *how* to inspect by poring over the main batch — literally the screen system. Incidentally, by using the screen system for training, friend Gertrude would lose far less time; it takes only a second's interruption to stick a couple of self-explanatory defectives into the training box.

There's little need of laboring the point. How much better it is to get the eyes, the mind and the consciousness so thoroughly accustomed to what is acceptable that the unusual, the oddity, the maverick will ring the bell. What difference whether the piece is defective because of a dent, a split, flaky plating or tarnish? It's defective — it's not acceptable — so toss it out.

An electronic gadget illustrates the screen system. This is a device which with a battery of electric eyes scans freshly engraved bank checks. The apparatus is "mastered" with a carefully pre-inspected, perfect check form. Then the check forms from the press are fed through the scanner. Any smooch of ink, dirty paper, die misplacement, thread, hair or dust or any sort of uneven printing reacts on the electric eye system and the defective check form is ejected from the scanner. The instrument does not question why such a particular defect or what sort. It is "used" to perfect checks and rejects any imperfect check no matter what the reason.

Sorting Slows Down Inspection

One of the monkey wrenches inspection management commonly throws into smooth, skillful, 100 per cent visual inspection operations is the demand that the rejections be classified. Put the splits in this box (we want to get a report back to the press room) and the off color pieces here (they can be stripped and replated; besides, the plating room ought to know about it) and all the dents and bent lips over there (that new conveyor I griped about does all that damage). And so forth.

So long as an inspector merely needs to extract the bad, the defective, the shoddy or the substandard from the good work, high efficiency both in speed and clean inspection is obtained. Add a classifying job, set the inspector to worrying about this particular kind of a defect and just that sort of scratch, and the production rate drops. Furthermore, the quantities of actual defectives that "get by" an inspector will increase.

It is far better for the inspector to work ten, twenty, thirty minutes or an hour steadily separating the goats from the sheep, simply following the screen system. Throw *all* the defectives in one till. Then stop inspecting for a few minutes and make a special of sorting out the defectives into the required classifications. Incidentally, a few "good" pieces that acci-

dentally slipped into the defect box will be saved but, by the system of making a special stint of sorting defectives, much fewer defectives will have previously slipped through into the good work. Some shops are wise enough to use "salvage" inspectors whose main duty is to classify out defectives from reject boxes. In those shops the inspector assigned to routine, 100 per cent visual screening (frequently on piece rate or incentive) has only a "good" box and a "reject" box — no set of classifying tills.

Lighting an Important Factor

Much eyestrain and the resultant weariness, numbing drowsiness, if not downright exhaustion can be avoided if, in the average shop, better attention is paid to lighting. It is hard to say whether the lighting of 100 per cent visual inspections should be approached more scientifically or more practically, for some illuminating engineers and experts (who don't, incidentally, sit hour in and hour out inspecting shop products under the lighting systems they recommend) seem to know the theories and formulas but, somehow, too little about human beings in the form of inspectors.

The greenhorn, the newcomer, at visual inspection usually demands (without benefit of technology) the brightest, most direct light possible. He likes it shining right down as close to the work as possible. Ask even an experienced inspector about the lighting and he will usually complain that it is inadequate. It seems to be a custom among inspectors, much like the farmer's habit of always complaining about the weather.

While bright light from overhead direct on the work may be desirable — at times necessary — and while it, of itself, may not tire the eyes, it is the matter of *reflected* light that is forgotten. Direct overhead light is shaded. like Nature's sunlight, by the eyelids and eyebrows Nature provided. But the reflected light bounces *upward* from bench tops, apparatus and workpieces. Nature did not provide special protection below the eyes.

The modern tendency is to use reflecting fluorescent units above the work place. But fluorescent light is cold, brilliant, hard, on many types of work; the old-fashioned yellow carbon light might be softer and kindlier on the eyes. Inspection management might give more attention to the admittedly

ghoulish green mercury units which do, however, have the knack of accenting the third dimension like depth, as in the examination of highly polished surfaces for scratches. Methods of diffusing direct light help many times — ground glass screens or louvre arrangements as shades. If the building facility of a white ceiling permits it, indirect light on many occasions is the answer to eye tire. Some situations allow for direct lighting units to shine on the work not only from above but from a little *behind* the inspectors. The reflected light then will seem to bounce *away* from the inspector's eyes.

A foot-candle meter perhaps should be used. Let it measure the intensity of light at the bench top, at the workpiece or hand level and at inspector eye level. Try turning it over to see if it will register the intensity of the reflected light bouncing up from below. As a very general figure, lighting intensities for most visual inspections probably should not be lower than 75 foot candles at the work nor seldom higher than 200 foot candles.

One other artificial illumination factor aiding and comforting vision is frequently overlooked. To have lighting close to and beating directly down on the work is all right, but it is not enough, no matter how intense it may be. The room or area should have general lighting around and especially above the direct purpose illumination. One of the reasons the spotlight type of bed lamp puts you to sleep so readily at night before you finish even a page of reading is because the ceiling above is black and the walls and everything else in the room but the book you are looking at are gloomy. Such illumination causes the eyes to tire quickly and drowsiness creeps on. Inspection areas should have "general" lighting, about and above the direct lighting, somewhere between 20 and 50 foot-candles in intensity.

The preceding discussion on lighting has been presented dogmatically for brevity's sake. It certainly makes no pretense of being professional or expert. Acknowledgedly, it is subject to disagreement. But it has been included deliberately in the hope that more and more practical and open minded study of the apparent peculiarities in inspection department illumination will be made, more experimenting done, perhaps with less foregone conclusions on the subject, arbitrarily accepted, to the end that maximum efficiency and minimum eye weariness will be reached.

Lighting Should be Specified in Appearance Standard

The use of light is important many times in establishing or displaying standards. One of the touchy subjects in 100 per cent visual inspections is the matter of finish, such as nickel and chrome plating, paint and enamel. Color is another trouble-maker, the exact shade of dye, stain or lacquer, for instance, being the subject often of almost bitter dispute. Plated pieces may be examined under tungsten lights in the plating room and a decision made there that their "color" or appearance sets the standard. The same two pieces can look entirely different upstairs held up by the window in the boss's office. In fact

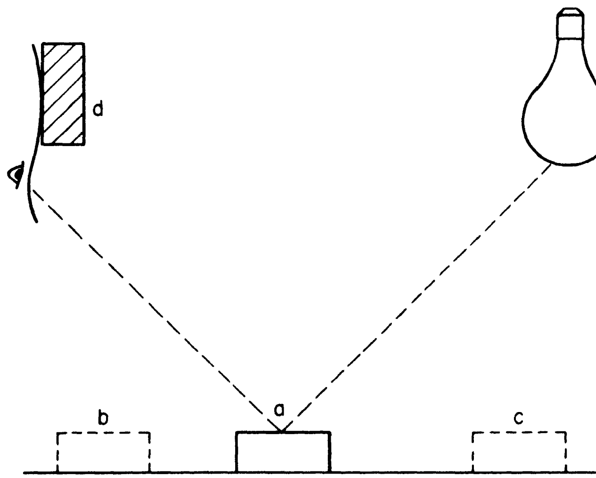


Fig. 7. When inspecting a work-piece for color, the same type and intensity of light should shine on the work being inspected as shone on the master. The angle of incidence should also be the same.

the two may not even look alike in daylight. Take them over under the fluorescent fixtures and the high light intensity at an inspection bench and a third opinion might be formed. Incidentally, under the same light they may not seem the same a few hours or a few days later; perhaps they sparkle less. Factory dust, vapor or oil film has already settled on the samples. It is good practice to wipe a visual inspection sample clean before using it as a standard.

To be completely technical about setting standards of abstract appearance or color, the same type and intensity of

light source should shine on the work being inspected as shone on the example, "master" or standard originally offered the inspector as a guide. Even the matter of angle of incidence is important. An attempt to delineate what is meant appears in the diagram of Fig. 7. If the master standard has been studied at position *a*, the work should be inspected at the same location. To examine the standard at position *b*, for example, and the work at position *c* might produce different appearances or apparently different shades of color (because of the variable angles of incidence and reflection) and work might be either rejected or accepted in error. To maintain the exaggerated technical perfection that Fig. 7 suggests, the inspector's forehead could rest against a "stop" as at *d* in order to maintain the optical angles. Furthermore, the wattage of the lamp should neither be increased nor decreased after the master has been observed.

The above is of course cutting things pretty fine if the suggestions are followed literally, but if practice is sufficiently close to theory, many petty shop wrangles and errors over rejections may be avoided.

At best, any human, over a period of time, will unconsciously modify the standards theoretically set for visual inspection decisions. On strictly borderline work, what is acceptable today may be rejected tomorrow, or even an hour from now. Another time, the inspector is more self-righteous than slack and his standards are temporarily tightened up. All inspectors' opinions (and that is all that visual inspection of marginal work is: opinion) should be refreshed, perhaps daily, with reviews of the concrete standards. Another way to realign standards in the mind is to reinspect the work in the "reject" box.

100 Per Cent Inspection Doesn't Produce 100 Per Cent Results

It should be remembered by anyone who has anything to do with 100 per cent inspections, either visual or manual, that 100 per cent is not necessarily (if ever) quite 100 per cent in results. If defectives are present in a batch, even the most expert inspector is bound to miss some of them at least once in a while. Where only a scattering of defectives exists in a large lot, the situation is akin to hunting a needle in a haystack and if there is an abundance of defectives to be culled out, it is like brushing white dog hairs off a blue serge suit.

A few figures compiled by check sampling* in 1949 indicated that 98 per cent efficiency was a pretty good figure. In other words, if 100 defectives were known to exist in a lot of, say, 5000 pieces or more, a good inspector would find 98 of them and miss 2 defectives in ordinary routine visual inspection work. Other tests disclosed efficiencies as low as 80 per cent. In one carefully supervised survey of normal 100 per cent combined visual and gaging inspection, 68 defectives of a known 100 were uncovered by a group of inspectors, working at normal incentive speed, and 32 were missed. The lot of some 30,000 pieces total was then delivered to a second squad of regular inspectors. Of the 32 defectives still remaining this second group found 18 and let 14 slip by. A third group picked up 8 of the 14 and missed 6. Finally a selected squad of expert inspectors tackled the lot, taking all the time and care they wanted. They picked out 4 of the 6 but failed to uncover the remaining 2 defectives.

Factors That Impair 100 Per Cent Inspections

There are several reasons for human failure in 100 per cent inspections. The greatest enemy perhaps is monotony. Some certain human attribute seems necessary, some sort of patience or peculiar stamina, to withstand the relative boredom of the repetitive series of inspection motions. Coupled with that kind of stamina should be also a degree of natural conscientiousness. If an inspector feels he hasn't those qualities, if 100 per cent inspection makes him nervous, bored and impatient, if a don't care attitude develops, he should doubtless seek a transfer to other work.

Even from the best, the most alert inspectors, fatigue steals efficiency. You may be conscientious, you may wish to work your best, but somehow in spite of you, after a while, the mind quits making decisions, the optic nerve evidently numbs and the retina becomes paralyzed, even though the hands obediently continue with the required motions. Sensible inspection managements recognize this sort of uncontrollable inspection fatigue and arrange for periodic recesses or changes of work every hour or so. The relaxation need not be long — a few minutes perhaps — because the human engine recovers quickly.

A third factor affecting inspection efficiency is ineptitude. Some people, otherwise completely normal, intelligent, conscientious and able, simply cannot inspect and do it well. An inspector should seek a transfer away when, after a reasonable apprentice period, he appears to be truly inept, awkward, on 100 per cent inspection work.

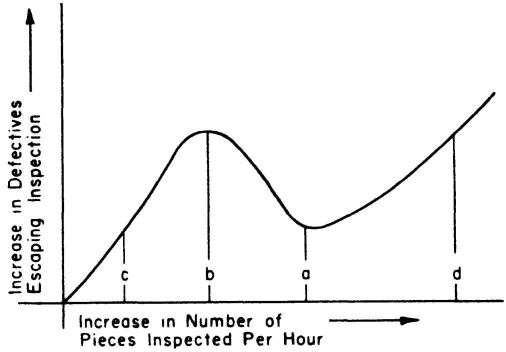


Fig. 8. The curve shows, for one particular inspector, the relationship between number of pieces inspected per hour and number of defects escaping detection.

Optimum Rate of Inspection

The result of a series of studies on the rate of inspection appears in the "curve" for one inspector in Fig. 8. A program was arranged whereby this inspector, as one example, assigned daily to the 100 per cent visual inspection of the same item, worked first very slowly and then in increments of every half day increased the pace of screening production. A measure of the number of defectives that "got by him" was devised through a careful sampling of his "good" boxes.

As the chart in Fig. 8 clearly shows, practically no defectives escaped him when he was inspecting very, very slowly. As the pace was stepped up, more and more defectives appeared in the good boxes. However, as the rate was further increased, a decrease in the number of defectives escaping into the "good" boxes occurred. The point brought out by the curve is that the inspection efficiency at production speed *a* is better than at production rate *b*. In fact it equals the inspection efficiency of the much slower production at *c*. Again it took a further increase in production pace to rate *d* to get back to an inspection inefficiency as bad as at *b*.

Many times alarm is felt over inspection inefficiency, over the number of defectives escaping through the screening, and orders are issued to slow down the pace. In the case of this particular inspector, if this action were taken at production rate *b*, (or *d*), slowing down would reduce the escape of defectives, but if the decision were made at production rate *a*, a decrease in speed would increase inspection inefficiency.

Improving Mechanical and Physical Circumstances

Recognition of the part that monotony, fatigue, ineptitude and rhythm play in inspection work should lead to better training and instruction, improved mechanical and physical circumstances surrounding an inspection job, improved analyses of inspection job ratings and incentives or finally, where it exists, to the recognition of a lack of aptitude for the job and subsequent transfer out of it.

Speed and physical handling, particularly of small pieces, in 100 per cent visual inspections can be aided by the use of inspection trays. Ordinarily these are metal trays shaped like a household dustpan with the handle off but somewhat smaller in length and width. Using both hands the inspector scoops up a layer of the parts from the pile on a bench or out of a box and, by shaking and rolling the parts on the tray, detects the defectives and picks them out.

A more modern trick in connection with 100 per cent inspections is to sit inspectors on each side of a belt conveyor and arrange for a steady flow of the parts, subassemblies or assemblies onto one end of the belt. As the pieces travel by, the inspectors pick off the substandard work. Inspectors are stationed at the regular materials handling conveyors with the same purpose in mind. One example is the inspector working at the end of a bottle-washing machine picking off chipped, cracked and dirty empties.

In a somewhat similar manner, inspectors watch the output of continuous processes like wire drawing and insulating, the rolling out of plastic, rubber or metal sheets. Or at the fabric rolling off a loom. Visual defects are "rejected" by chalking the defective stretches of product or they are marked with a spray gun.

Inspection of Large Single Units

Many visual inspections cover larger single units like refrigerator doors, automobile fenders, radio cabinets, television

tubes and the like. Usually the inspector is stationed directly after a continuous enameling or varnishing operation, checking off with crayon marks or paint blobs the unsatisfactory units. In textile mills the fabric is made to travel over special inspection perches in front of the inspector.

Here again the philosophy of the screen system, of the trapper story, is relied on. The inspector need not force his eyes to search each square inch of the surface like Sherlock Holmes going over a carpet with his magnifying glass. His glance should take in a unit of area, if not the entire area, at once. His eyes should be so accustomed to the appearance of satisfactory areas, as units, that he readily detects even rather minute defectiveness occurring at any point in the unit area.

The sort of inspections just described involve those situations where, because of the area, size, bulk or weight of the workpiece or material, it is easier to send the inspector to the work than it is to bring the work to the inspector. Many times, too, as in the case of conveyor belt inspections on smaller parts, there is the profitable matter of saving production and handling time in a manufacturing cycle by not bottlenecking the product for 100 per cent inspections. But the inspector must not lose sight of the principles of visual inspection that apply.

Just because the inspection is performed somewhere out on the line is no reason why the lighting should not be correct and uniform for the inspection purpose. Following the reasoning illustrated by Fig. 7, the inspector should maintain a definite location in front of the work passing by. (Perhaps he should paint a target or "box" on the floor). Everything about him should be as relaxed as possible except that part of his body above the nose. He should take whatever definite steps he can to avoid or eliminate tiring physical distractions — drafts, noise, interruption — as much as he would at bench inspection.

Checking for Several Kinds of Defects

A great many 100 per cent inspections are made on articles where there are more than one or two simple evidences of defectiveness to be detected. As an example, consider switches or relay mechanisms. The visual specifications on one such mechanism called for the plastic container or shell to be free

of burrs, chips, checks or cracks. An inside wall or partition should not come from the mold broken through. The switch lever must be in the off position and an adjusting screw is to be tight and securely soldered. Certain lock washers are to be surely compressed to the point of flatness.

Here are a half dozen specific elements to be looked for on each switch, a situation where a single embracing glance will not suffice and, to a degree, the screening system fails. The eyes must travel from item to item — take an inventory of each piece.

This operation, then, calls for the study of about a dozen types of defects, any one or all of which may happen to show up on any unit inspected. Some of the defects are fairly self-evident if present, such as the location of the adjusting screw; other defects involve close and critical examinations, (is the adjusting screw really tight — securely soldered?).

Establish an Order of Checking

The inspection of this part illustrates another set of worthwhile habits the inspector should acquire. As the eye and mind range more or less automatically over each piece, the items or elements making up the inspection should be taken each time in the same order. Look at the bakelite case, for instance, always first and then at the switch; next examine the set screw, the soldering, and finally the washers. Follow the same order, mentally and physically, with each succeeding piece. Don't look at the soldering first, on one piece, and then at the lock washers first on the next piece; in other words don't let the inspection procedure become a hit or miss jumble of glances like a grasshopper jumping around a field.

In some factories, a sort of operation sheet or typed set of specifications is supplied the inspector. Where it is not, an inspector would be wise to write up his own order of events, his own operation sheet, and review it, say, every day to be sure he is not overlooking an important item.

The inspection of a switch is, perhaps, simple compared to the inspection of an auto truck cab, for instance. Usually in an automobile plant the vehicle comes along the assembly line equipped with an inspection card, a check list in other words, and the inspector is required to put a pencilled okay after each item as he completes each detail of the inspection. Sometimes there are over a hundred items listed — windshield, door latch,

horn button, dash fuse, lock washers under sill screws, and so on through the innumerable list of things a truck driver expects to find, operate and give no trouble.

Final Inspection

If the 100 per cent inspection procedure is not used or condoned anywhere else in a factory, it is liable to be adopted for the inspection and screening of the products made and sold, before they are packed for shipping. The inspector assigned to final inspection lives, in many ways, in a different climate and faces a different set of problems than he would likely find in 100 per cent inspections tucked in among various steps of the manufacturing process.

The primary purpose in the final inspection of a shop product is, of course, to make sure it is "right" before it is packed and shipped. The products passing final inspection are what the customer pays for. The examinations of components at patrol and batch inspections are not under the same onus, for they may be reworked, salvaged, scrapped or otherwise disposed of and some of them never reach the customer. People know of a company from magazine, newspaper or radio advertising. While these sources may influence them favorably, their real judgment, in the last analysis, is based on the product itself, and the company's prosperity depends on the favorable reaction its products make on its customers. Hence, an atmosphere of tension, to some degree, usually pervades the final inspection area.

Mechanically, final inspection normally can be divided into three classes of observations: visual, manual and testing. In another sense, there are three other classes of attention. Foremost of course, the final inspector wants to be sure no blemish or defect or missing part will gain customer disapproval. Secondly, assuming all the components and subassemblies were satisfactory as each left its process or operation, the inspector looks in particular for errors or damage that may have been caused solely in the final assembly operations. Final inspection is usually the only check on assembly department quality. Third, he searches out hidden defects or possibilities of future breakdown of the product. For this latter purpose, the inspector may rely on special tests or on experience that develops an instinct for trouble or hidden substandard work.

The final inspection of many products consists totally or solely of visual inspection. Other products demand final gag-

ing, testing or manual inspection in some form. In the latter event, it is of course a matter of efficiency that the detail of visual inspection be done as the manual inspection is performed.

Final inspections are most usually 100 per cent inspections. Each and every unit of a product is examined or tested. Some products, however, are so uniformly produced that sampling inspection can be used. Where a shop makes machine screws, for example, the inspection of a random hand full of screws can designate the conformance of the entire order. The final survey of other products involves what is called destructive tests. Certainly it would not be feasible for a confectionery manufacturer to bite into each candy bar to be sure of its goodness before it is wrapped and packed. Hence, sampling must be resorted to and depended on in many circumstances. Substitute or equivalent tests can be devised many times. One way of testing ball bearings might be to give them a "life" test — running each bearing for many, many days under nominal load. Commercially however, they are run for a few seconds in a dynamometer vibration tester. If the needle of the tester swings over too far, indicating excess vibration, it is known from previous research that the bearing will not last as it should in ordinary service and it is discarded.

Final inspections are made on a wide range of products, varying in size and type. In one shop the final inspection operation is performed on a thirty-ton machine, perhaps on a turbine, or on an intricate packaging machine. In another shop it may be office or household appliances, furniture, or eye glasses. Again, the final inspection may face smaller articles produced daily in hundreds and thousands like ball bearings or fountain pens, socket wrenches or snap fasteners.

More than anything else, perhaps, the visual inspection of finished products has to do with appearance, with the impression the product will make on the customer's eye. For this reason, the final inspector must know thoroughly his shop's standards for finish. In detail, he should become expert at distinguishing, for instance, between a lively and a lifeless painted or enameled surface and know what happened back in the shop to cause an insipid appearance. Similarly, polished and plated and buffed surfaces are either cloudy or bright. If the product has, for example, two or three different nickel or chrome plated plates or strips on it (frequently only as a

matter of decoration to lend merchandising appeal) one of the plates may be dull or cloudy and another brilliant. The contrast will give the product a shoddy appearance, and the reason probably for the trouble is that the pieces were plated and buffed at different times in the shop, one of them in substandard fashion.

Rust, corrosion, dirt and grease are taboo on finished products, at least to any appreciable degree; likewise dents, scratches, pits, digs, nicks, rub and score marks, and blistered and peeled spots. The inspector is usually instructed to look for sharp corners, knife edges, splinters or any similar condition on the product that might damage the customer's person or property. The inspector is expected also to look for missing screws or missing parts. The assembly and shipping specifications of a motor, for example, may call for a Woodruff shaft key to be supplied and a set of toe bolts. Such parts, frequently contained in a tagged cloth bag wired on the motor frame, are easily forgotten by assemblers or get torn off. Other items include illegible lettering on name plates or the undesired presence of tape, metal strip, wire or other material used in the manufacturing or handling of a product that have crept through on the components.

Testing in Final Inspection

Closely akin to gaging and manual inspection is what might be called testing, for the want of a better word. The inspection department is called on to make many kinds of laboratory and functional tests on manufactured products. Electrical tests of various kinds are quite common. There are temperature tests, life runs, tensile and hardness checks, speed, time and flow measurements.

Detailed descriptions of even a fraction of all the sort of tests modern products are subjected to would require a whole book itself on the subject, if not virtually a complete encyclopedia. But on the directly ensuing pages a series of photographs with descriptive comments illustrate a few industrial samples and help to establish, perhaps, the atmosphere for a short discussion on testing as an inspection specialty.

Follow Instructions Implicitly in Testing

The first rule in testing, so far as the inspector is concerned, is to follow implicitly, religiously, the instructions the laboratory or the engineers have issued. His responsibility is to read

Fig. 9. Circuit breaker and relay unit being subjected to electrostatic and load tests which are indicative of actual performance.

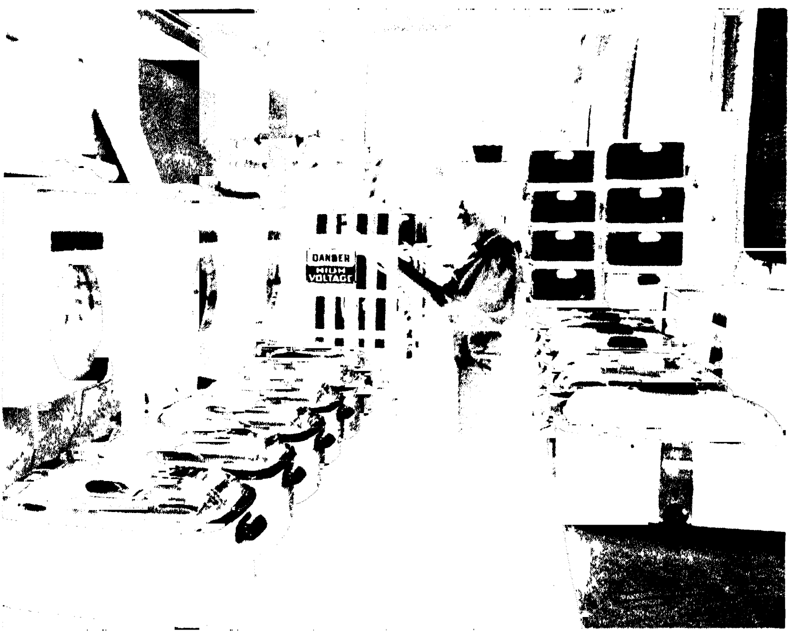


Fig. 10. In this test the roaster is brought up to a succession of operating temperatures and the action of its thermostatic control checked so that the housewife can be sure that the temperature control knob has been accurately calibrated.

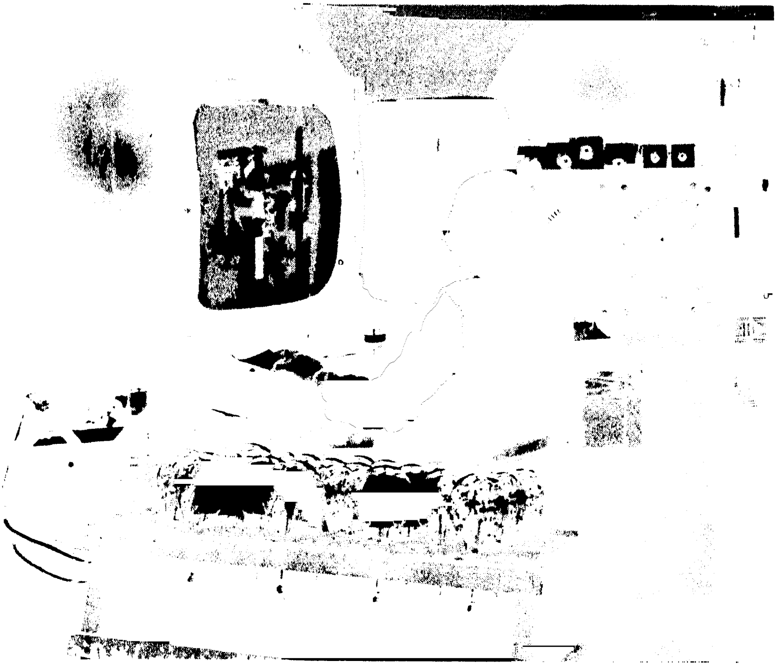


Fig. 11. Measuring light-bulb output by photometry.

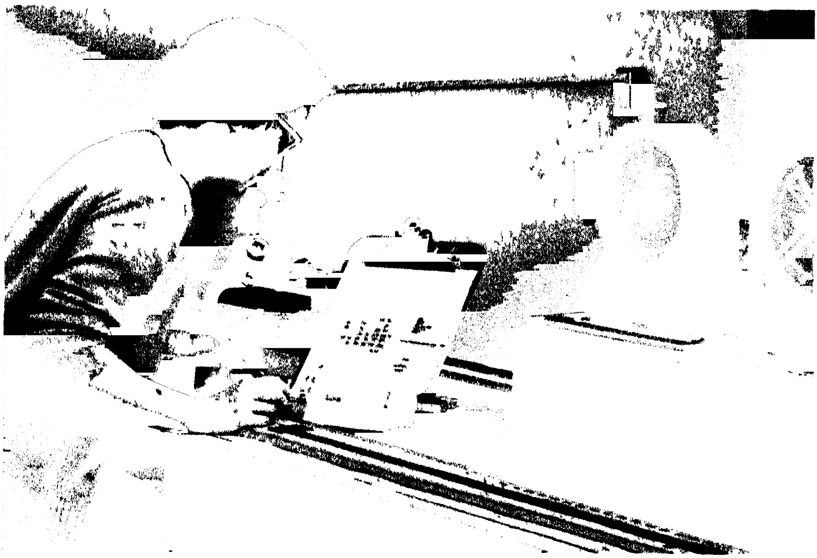


Fig. 12. Examining the surface of a metal to determine the grain size.

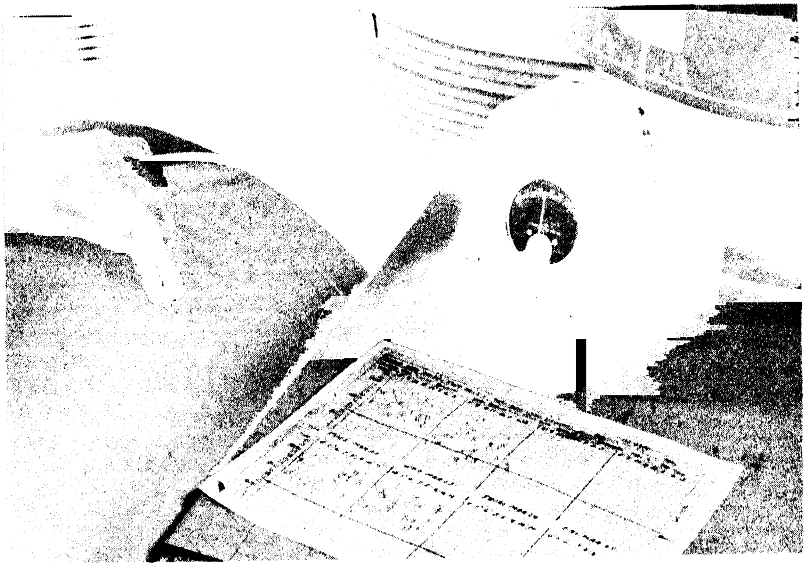


Fig. 13. Testing the thickness of an enamel coating. A thin coating means sub-standard appearance and probable failure through rust and corrosion. Too thick a coating means wasted enamel and possible chipping and peeling of the coating from the base-surface.

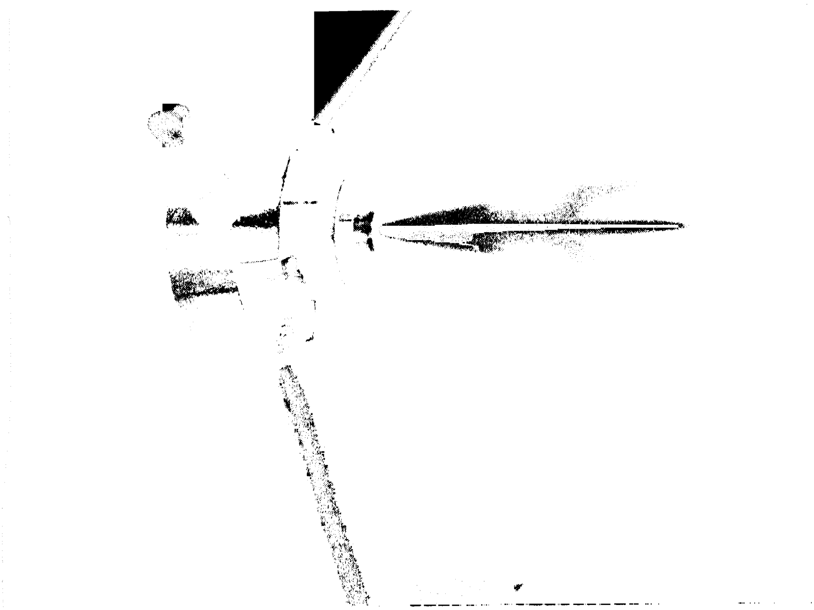


Fig. 14. The conformance to specifications of fuel oil spray nozzles is determined by inspecting the spray pattern.

Fig. 15. In some factories, an inspector must be familiar with specialized test equipment for a variety of products.

the instruments faithfully, make the observations required and get the data and figures specified.

If for no other reason, the matter of personal safety and the eyes and limbs of fellow inspectors may depend on following the rules exactly. Many tests are of extra severity, so-called. Electrical products may undergo a 10,000 volt ground test; valves are tried under 1000 pounds per square inch hydraulic pressure; wheels are revolved close to bursting speed; a chemical test may involve sulphuric acid or ammonia.

No, the test bench is absolutely no place to indulge in flights of fancy or personal research or to disagree with the technicians. Neither is it a secure little nest in which to catch up on last night's sleep.

Understand the Basis for the Test

The inspector will work more intelligently if he makes a point of finding out the reason and basis for a test. Some tests otherwise seem very obscure. An essential feature in grinding wheels, for instance, is the porosity of the wheel. If too fine a grit has been used accidentally or too high a proportion of binder, the air spaces between the particles of grinding grit will not be large enough and the wheel will glaze over when it is put to work. This porosity is determined by securing a specific gravity comparison, e.g., weighing the wheel in air

and again under water. Unless the theory of this test is known it seems absurd to dunk a wheel in water and weigh it.

The various tests required are devised usually by the laboratory or the engineering department. Sometimes they are required and specified by the customer. Occasionally the research direction and assistance of a consulting firm or college is hired for the purpose. There are many occasions, however, where an inspector can and will devise special tests and methods or suggest revisions, even the elimination, of existing routines. A chance to work and study under research laboratory conditions is almost always valuable for an inspector. The American Society for Testing Materials (A.S.T.M.) publishes many pertinent articles and pamphlets as well as handbooks and the inspector can well be advised to get acquainted with this type of literature if only to get the atmosphere, the theory, some of the general techniques and an idea of the potential errors in testing.

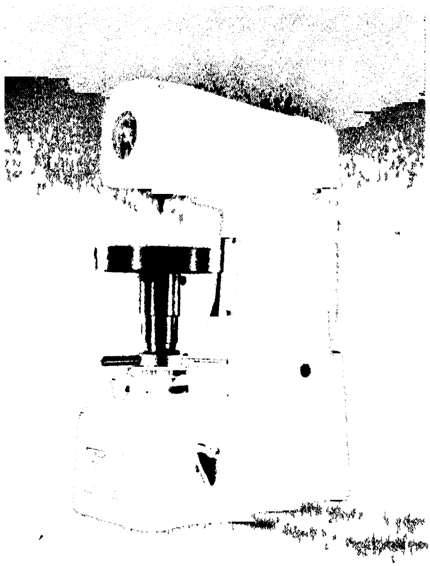
Testing for Hardness

One garden variety of test very common in the inspection routine is for hardness. Without going into the ramifications of heat treating, tempering, annealing and hardening or what the metallurgical property of hardness is, one or two principles behind hardness tests can be discussed here. The hardness of a given material can be thought of as the degree to which it resists penetration by other substances. The diamond is the hardest known substance followed by such synthetics as corundum, sapphire and carbide.

Most usually the hardness of a part or material is tested by forcing or indenting a harder material into it and measuring the indentation. Equipment making use of the indentation principle has the following trade names: Rockwell, Brinnell, Vickers, Monotron and Herbert Pendulum. Another principle used in hardness testers (exemplified by the Scleroscope) is to note the extent of rebound of a hardened bobbin or hammer from the surface being tested.

On the equipment using the indentation principle (like Brinnell and Rockwell), the major difference is the method of measuring the degree of indentation, the Brinnell depending on a microscope and a scale for measuring the diameter of an indentation made by a hardened steel ball or a diamond point while the Rockwell measures the depth of indentation with a

dial indicator. On each type of equipment, mechanical means are available for "loading" the indenting ball or diamond under known weight or pressure. Tables are supplied with this type of equipment with which indicator or microscope and load readings can be translated into hardness units.



Courtesy of Wilson Mechanical Instrument Co

Fig. 16. Standard Rockwell hardness tester.

Procedure in Making Hardness Tests

Specific detailed instructions as to how to use hardness testers should be gotten, of course, from the manufacturers of such devices. However, there are several general errors an inspector is liable to make in using any type of hardness tester, so that enough detail in connection with using the Rockwell apparatus, Fig. 16, will be described here to bring out some principles.

The workpiece is elevated on the table by means of a handwheel to bring it firmly against the penetrator point. The Rockwell indicator has two hands or pointers. By means of a hand lever an initial or light load of 10 kilograms can be applied, the small pointer indicating when this is accomplished.

Applying this initial or light load overcomes a lot of potential small errors and deflections due to surface roughness, initial elasticity and factors other than hardness existing in or about the workpiece. The penetrator starts a slight indentation as the initial load is applied and the main — large — pointer is zeroed on the indicator by turning the indicator's bezel.

The inspector can assist or hinder the accuracy of his final readings at this point by the way the workpiece is mounted on or rests on the instrument table. Remember the instrument can measure deflection as well as skin penetration. The workpiece must be on a solid foundation. If it is not flat — if it is curved, warped or arched, the hardness tester's penetration reading may be modified, weakened, by the "spring" of the workpiece. Sometimes it is necessary to shim up solidly under a workpiece and be sure it can't tip, bend or buckle a little. The instrument itself must be on a solid foundation that is free from vibration. Vibration can shake the penetrator down into the workpiece further than it should go for the sort of static test it is supposed to yield.

Next, use the hand lever and apply the major (main) load. The big indicator hand will swing slowly. Hold the major load on for about two seconds after the indicator comes to rest, then lift it off. The big hand will recede slightly, the result of internal spring-back in the metal of the workpiece. The net indicator reading is taken.

The standard Rockwell indicator is equipped with two scales, the C scale and the Rockwell B scale.* A 1/16-inch steel ball is used as the penetrator with the B scale and a 100-kilogram load, and a sphero-conical diamond Brale point with the C scale under a 150 kilogram load. If the workpiece is so soft that the C-scale reading is less than C-20, change to the B scale, the ball penetrator and the 100 kilogram load. In recording Rockwell readings always register the scale used.

Where the C scale and the Brale diamond point is used, the diamond must be examined, preferably before each set of tests is made, because the diamond is fragile and may become cracked, chipped or even shattered. Be careful not to rap the side of the Brale point with the workpiece.

* Rockwell superficial (so-called) testers can be secured which load 3 kilograms initial and not more than 45 kilograms working load on the penetrator. Hence the indentation is more shallow and this type of tester can be used on thin stock.

Master test pieces of known hardness are supplied with the hardness tester so that its calibration, accuracy and repetition can be checked.

Where the hardness of a specimen is unknown, test with the diamond point and C scale first. A glass hard surface could damage a steel ball penetrator.

The condition of the surface of the workpiece is important. The penetrator can register on the ridges of surface roughness or on scale or dirt and give a false reading. For accurate work it is safer to polish smooth at least the small area of workpiece which is to receive the indentation.

Hardness is sometimes tested with standard, specially made hardness testing files, the hardness numbers of which are usually stamped on the shanks. In using hardness files, calibrate yourself by filing on workpieces of known hardness; strive to file at a consistent angle, at the same uniform speed and with the same pressure. If the file cuts the workpiece the latter is softer than the file; vice versa if the file makes no impression. To measure the degree of hardness in a workpiece it is usually necessary to use a series of files whose hardness are graded about 10 hardness numbers apart.

Reasons for Establishing 100 Per Cent Inspections

But before the general subject of 100 per cent inspections, including testing, is left behind, a couple of aspects of management economics might be broached. For the most part, 100 per cent inspections are adopted as a sort of defense mechanism to assure product quality or, what is more important, to win buyer confidence. In competition, a product attains its position and a manufacturer wins or loses by a certain combination of market price, manufacturing cost and the commercial quality achieved for that cost and necessary for that price level. If 100 per cent screening of the product adds too much to the cost, and the price has to be increased, the manufacturer may forfeit his leadership. He may then cancel the screening, risk substandard products and lose consumer confidence in the attempt to meet price competition.

The obvious answer to the quandary is to take steps—*action* — in the manufacturing process aimed to prevent the manufacture and appearance of substandard components, subassemblies, yardage or units. It is an axiom that the act of screening inspection, though perfectly performed, cannot inspect quality *into* a product. It merely sifts out the substand-

ard. In industrial terms, the results are either high scrap losses and a decrease in total output, or they are costly salvage operations and/or selective assembly. Screenings, detailing, 100 per cent inspections cannot occur until *after* manufacture and as far as correcting fundamental errors is concerned, they are like locking the barn door after the horse is stolen.

Another reason offered for 100 per cent inspections is to lower assembly costs. Any assembly department is expected to be to some extent a screening area; any assembly operator should detect and toss aside defective, rejectable or substandard components and units. On the other hand, there are situations in which cost studies can reveal that it is more economical to make a special operation of having inspectors screen off all defectives and leave the assembly operators completely free for their own work. In other words, the addition of inspection specialists to the payroll may be more than offset by the saving in assembly hours or a reduction in the number of assembly operators.

Coupled to the above thesis is the occasional circumstance where a faulty process cannot be brought into line fast enough to eliminate the necessity of 100 per cent inspection. As an example, the sudden demand, the absolute necessity, for clear, flaw free, undistorted glass for television screens caught the glass industry unprepared as far as the process of making huge quantities of clear vision television "tubes" was concerned. The percentage of substandard glass that seemed bound to creep through simply had to be inspected out. A machine wears out and gives away suddenly and for a while it cannot make a high enough percentage of parts to required tolerances. Weeks or months may elapse before a new machine or suitable replacement parts can be obtained. Under such conditions, screening is justified as a temporary expedient.

The trouble with temporary, emergency measures is their tendency to become permanent. Government agencies created to deal with an emergency are good examples. Try to get rid of them. Nothing exemplifies immortality, as Secretary Byrnes said, like a government bureau.

Drawbacks of 100 Per Cent Inspection

Setting up 100 per cent inspection exerts a peculiar "psychology" on manufacturing departments. Knowing that, if they do make substandard stuff, inspection will comb it out,

production people inevitably slacken their attention to quality and zealously concentrate on quantity, on making new and ever better production records, forgetting that it is the *net good* product that pays the dividends. The attitude is not unlike that of the young husband who is living "temporarily" off his father-in-law. As long as the old man foots the bills life goes on merrily.

Sometimes an attempt is made to justify 100 per cent inspection expense on the basis that from it reports are secured as to how much substandard product is actually manufactured. But, somehow, the reports seldom do much good. In the first place, under the best conditions, it takes time to complete 100 per cent inspections and get the reports, and the time lag is usually nearly fatal. To tell an operator on Tuesday that he made 8 per cent scrap last Friday has little effect. Yesterday is gone, tomorrow has not yet arrived; most of us shrug off the importance of today.

No doubt the best cure is prevention. Applying this axiom to manufacturing means engineering the process that is least likely to produce substandard products. If the blue print calls for $\pm$ .0005-inch tolerances it is nearly useless to manufacture such parts on a machine that cannot hold closer than $\pm$ .002 inch. However, the best intentioned, the best designed, and the best made equipment and machines "get off the beam." It is good manufacturing economics, for instance, to secure the maximum production from the equipment, machine or process, the most production with the least possible number of interruptions or shutdowns for adjustments, repairs or replacements whether it means sharpening a tool, dressing a wheel, reclothing a card or changing a set of rolls. But such practice, economically sound as it may be, does produce marginal if not substandard or actually defective products — at least a small percentage right at the time of adjustment.

Under the conditions, then, the man best located not only to detect the trouble but to inspect, and to sift out defective units is the operator. Let the necessary gaging, testing and visual inspection operations — the time for them — be added to his operating cycle. Why handle each piece all over again a second time at some later and distant 100 per cent inspection? Another axiom comes up here: the closer to the source of manufacture the decision is made in regard to conformance the better will be the over all quality.

The last few paragraphs concerning what might be termed the economics of inspection have been included for two reasons in particular. In the first place, the inspector soon comes to realize that there is something called statistical quality control which can be used to alleviate the burden of 100 per cent inspection. In the second place, it is always wise to consider the shortcomings of any system along with its favorable points. The inspector many times faces the problem not only of technology — what is the best gage, apparatus or instrument to use — but also of economics. He should question everlastingly. Is this inspection necessary? Could or should the operator do it? Must every unit be examined — 100 per cent inspection — or will sampling serve as well? In general, the more an inspector deliberately attempts to work himself out of a job, not in the sense of slacking or soldiering or buck-passing of course, the sooner he will be promoted to a better job.

Statistical Quality Control — An Inspection Tool

There are few manufacturing plants or shops in the country into which a new inspector could not step and not hear something said about "quality control" or "statistical quality control." In many factories, he would soon be introduced to sampling tables and control charts. Statistical quality control uses a mathematical and statistical approach as opposed to an offhand guess and makes use of that branch of applied mathematics based on the theories of probability. Quality control methods make use of a few samples to estimate accurately the condition of the lot or batch. There is no need to feel alarmed over the term quality control by statistical methods. The procedure is to go ahead and try quality control techniques. So that an inspector's shop contact with the subject will not be an utter mystery, there are many books available which will give him a good start on this somewhat special and separate technology. Two books which the inspector is advised to study are: *Quality Control,* N. L. Enrick, Industrial Press Inc., and *Statistical Quality Control,* E. L. Grant, McGraw-Hill Book Co.

CHAPTER 18

Process Inspections

The term "process inspection" is deliberately used here as a generally embracive expression. In manufacturing plants and industries across the country, the sort of inspection to be described or implied may be called by a variety of names and cover a number of specific types of inspection functions. Local terminology includes such names as batch or lot inspection, departmental inspection, terminal inspection, patrol, roving, machine or floor inspection. The name of the process inspection may come from the type of manufacture where it is performed, such as foundry, welding, assembly, lehr, strip or card inspection. You will hear about first-piece inspection or final inspection, of sampling and check inspections. The location often affects the name of the inspection, as in receiving or incoming inspection, conveyor or hopper inspection, stores or stock inspection. All of these are varieties or classes of process inspections.

Perhaps one orderly way of presenting and developing process inspection is to follow the general historical trend of events in inspection, as a whole. Almost universally, inspection started in industry as a 100 per cent final inspection. There came the time and the need for inspecting, examining, testing and culling the final product just before it was shipped out. Then, naturally, the economy of introducing similar inspections "down the line" on essential parts, subassemblies and operations became apparent, and from such experiences came what will be termed here "batch inspection."

Batch or Lot Inspection

Even in the most continuous manufacturing processes it has always been expedient to break the output up into more or less natural units of manufacture or production. The process in a wire mill for economy reasons is about as continuous as

any, yet the quantities of wire are eventually cut and subdivided into reels or coils for convenience in shipping and customer handling. So the ordinary mileage of wire in a reel becomes a sort of natural unit that is used back through the whole process for pricing, costing and inventory. Where castings are made, the contents or "heat" of a furnace may make up the natural unit for the lot size. The number of pieces a machine can make in an hour is sometimes a batch unit. The sales quota of a machinery manufacturer may be, for example, 240 machines a year. Hence, he plans to make up 20 machines every month and his lot sizes of parts, castings and subassemblies have a natural tendency to number 20 pieces of each kind.

The scientific study of lot sizes is a very important economic factor nowadays since it affects the purchase and use of equipment, the setting of incentive rates, machine speeds, tool and die life, set-up costs, quantity purchases of material, inventory requirements and a large number of other factors.

Other Factors Determining Lot Size

The above has been mentioned only to indicate that usually the lot or batch size has been established for the inspector by factors out of his control. Many times the inspector's batch size is determined simply by the number of pieces which happen to fill a tote box, truck or pallet, or by the number of yards in a roll. In general, then, the inspector adapts his procedure, sample sizes, timing and other factors to what the shop is naturally using in one form or another as batch units. Occasionally he is forced to be arbitrary and establish lot sizes of his own. He might decide, for instance, to inspect each half-day's production of a machine, whether it filled one or a dozen boxes or whether the half day's work represented one tenth or ten times the amount specified in a production control order. Next to actual box, truck or pallet counts — physical quantity units — some natural time subdivision is perhaps the favorite measure of lot quantities or units used in inspection.

Another factor which should wisely affect inspection batch size is the question of rejection. Usually the production department prefers its rejections in small doses. It is very possible, as an example, for a batch of 10,000 pieces to be rejected because too many of them are oversize. The produc-

tion department must then, perhaps, run the entire 10,000 through a machine simply to size down the percentage that is over tolerance. If, however, the lot of 10,000 had been subdivided into batches of 1000 each, it is possible that 7 of the 1000-piece batches, say, would pass sampling inspection and that production would need to rehandle only 3 of the batches since, by circumstance, most of the defectives happened to congregate in the 3 sublots.

As far as possible, the inspection department will render great assistance if it will insist on an attempt to establish as small batches as is possible or reasonable. Furthermore, each batch inspection should be made as soon as possible after the manufacturing operations are completed.

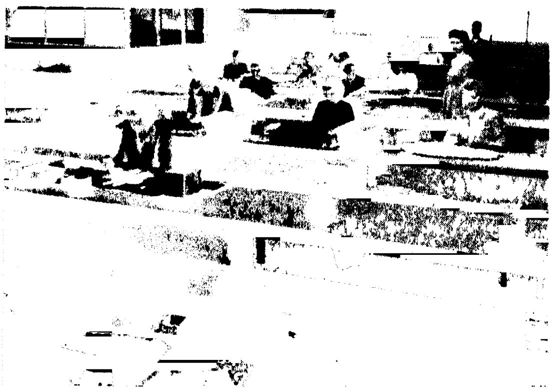


Fig. 1. Typical large batch inspection area.

Where batch inspection is an established factory inspection routine, the work is ordinarily automatically routed to an inspection station. Such a station may be a certain bench, a crib, or a room full of inspectors. It may be located adjacent to the manufacturing department or off on another floor; again, batch inspection occurs, in some instances, at the end of a conveyor line and, occasionally, right beside the machines. The more common procedure is to have the manufactured pieces taken from the machines in some type of pan, tray, box, truck or conveyor to the established cleaning or degreasing process and thence routed to the inspection station, crib or room. An illustration of a large batch inspection area appears in Fig. 1.

A number of suggestions, tips and rules have been given in the earlier chapter on 100 per cent inspection concerning some of the physical, visual and mental factors connected with quantity inspections, most of which can be applied to the inspector's individual handling of batch inspections.

Information Needed for Batch Inspection

To competently perform batch inspections the inspector should also be equipped with three general classes of information. He should be sufficiently conversant with all the preceding manufacturing operations to recognize quickly substandard work and to know pretty well what caused it. He should have, of course, up-to-date blue prints and specifications and be thoroughly instructed in the technical details connected with the immediate inspection. And he should have learned in reasonable detail where and how the parts will be used farther on.

Inspectors performing batch inspections usually handle a variety of parts and components and the requirements mentioned above should be constantly reemphasized in his mind. In addition, he should be conversant with the shop's general standards of manufacture and appearance. Where batch inspections call for the use of gages or measuring and testing apparatus, the inspector will, almost without exception, use inspection department equipment. Care must be taken, then, that inspection gages, say, compare as exactly as possible with production gages. If some variation between them cannot be avoided, the inspection gages should be more lenient than production gages.

Three Functions of Batch Inspection

Sampling and statistical quality control techniques are being introduced into batch inspection procedures more and more. As a result the viewpoint has developed that it is not always economic to try to make 100 per cent of the parts or products up to specifications. Some practical percentage deviation is allowed away from the absolute perfection of making every single component within tolerances. Hence, batch inspection has two main objectives. One is to detect substandard and out-of-tolerance work and the other is to determine whether or not the quantity of defectives in a lot has reached an unprofitable level. The third duty is to screen the poorer lots free from defectives.

As a general thing, in today's factory these objectives are attained by first sampling the batch, using a suitable sampling plan or table at some prescribed quality level, and secondly *detailing*, that is, 100 per cent inspecting those lots which the sampling plan does not accept.

Dangers of Monotony in Batch Inspection

In some instances, batch inspections are simply inspections of successive lots of the same part. In such a case, the bench layout, the facilities for handling the boxes or containers, the gages and testing devices, will remain the same, day in and day out. The inspector must be alert to the danger of over-confidence where batch inspection is of this repetitive and frequently monotonous nature. His own personal conceptions of the standards are likely to become dulled and blunted. If the standards at production are gradually relaxing, the inspector is liable unconsciously to start sliding down the same slope. If the print calls for a diameter to be, say .265 inch — .268 inch, he would more naturally notice occasional pieces of .2679 inch to .2680 inch if most of the batch came along .265 inch to .2655 inch but where practically all the pieces were .2678 inch, .2679 inch or .2680 inch he could more easily fail to observe .2681 inch or even .2682 inch work. White has a tendency to become gray, fine to become coarse and round to become oval and, if the transition is gradual enough, the inspector will fail to notice it. So, the batch inspector should institute a definite routine under which hourly, daily or weekly he pointedly refreshes himself by reviewing the standards; where he deliberately brings himself up short and checks his own inspection methods.

The same condition applies to gages, testing equipment and inspection apparatus. Unless there is an established routine for having the accuracy of micrometers and indicators periodically checked, they too will soon wear and become as sloppy as the inspector using them. Where an inspector uses a microscope regularly, as an example, how often does he deliberately stop and think to wipe the dust, sweat, oil and fog off the lens?

Dangers of Variety in Batch Inspection

Happily, batch inspection more often covers the examination of a variety of parts and materials and the shortcomings of monotony are lessened. Only, however, to have one or two

other potential dangers substituted. One is the decided tendency to be lazy about looking up specifications and standards; for the inspector to believe he remembers the details of the inspection from the last time he performed it. Is he sure, for example, that the tolerances weren't changed since the last batch came through? Better get an up-to-date print every time! The same type of slackness applies to gages and equipment. The particular gage is used, for instance, only on this particular component. It was accurate a month ago and it hasn't been touched since; why bother to have it checked!

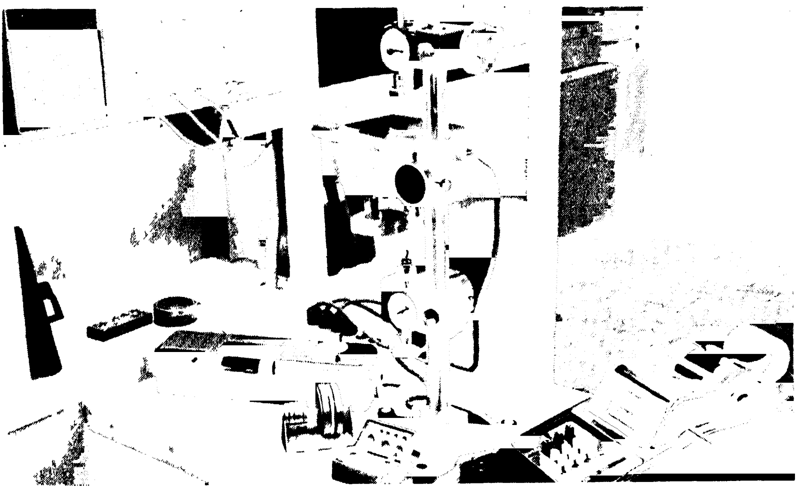


Fig. 2. Some batch inspection operations, such as those involving a certain type of coil spring, require many pieces of inspection apparatus.

The seasoned inspector watches one other element in connection with batch inspections of a variety of materials and components. It takes time, effort, sometimes a great many footsteps, to collect together the gages and apparatus necessary for a single type of part and to set it up ready for use. Sometimes it takes longer to make ready for an operation than to perform it and frequently the time loss is unavoidable. Figure 2, as an example, illustrates the collection of apparatus necessary for inspecting a batch of a certain type of coiled springs. To minimize this time and energy loss, the inspector and the department can make sure that intermittently used apparatus is conveniently stored in readily accessible loca-

tions. But more to the point, the individual inspector can materially help the situation by the manner in which he puts the apparatus away each time *after* he is through using it. A minute or two spent cleaning and readjusting apparatus just at the time he is finished with it can save an hour, perhaps, the next time he needs it. In fact, the apparatus usually can be stored away carefully set and immediately ready for use the next time. The worst thing an inspector can do is toss his apparatus into a cabinet the way a child discards his toys and runs off to other interests.

Patrol Inspection

Depending on local conditions, this type of inspection may be known as roving inspection, floor inspection, machine inspection, line inspection, departmental inspection and other similar names. It is almost literally the bringing of Mohammed to the mountain for, in patrol inspection, the inspector goes to the work, in contrast to batch inspection where, for the most part, the goods are routed to him.

Patrol inspections include not only a decision as to the conformance of products to specifications but also a preview or forecast as to how the operation will probably proceed. Being right at the source, the inspector has an opportunity to look for surrounding or impending causes for substandard work. At batch inspection the work is completed — sometimes long since done. There is more of an air of finality at batch inspection. The inspection operation is physically separated from the manufacturing operation. So batch inspection decides only that the goods do or do not conform and that they can or cannot proceed in their present condition to subsequent production or assemblies. The evidence is all in at batch inspection and is represented by the goods themselves; in a patrol inspection an inspector can be guided in his decision to some degree by circumstantial evidence.

Inspection Should be Timely

Inspection in general, to be most effective, should be timely. In the sense of uncovering and remedying substandard design, manufacturing and production conditions, the inspection of a run of product occurring hours or days after the work is done has lost, perhaps, its most valuable element. True, a post mortem inspection will cull out defectives, scrap and junk and present a cleaner product to the next operation, to

assembly or to the customer. This is something gained, of course, but it is probably the most inefficient manner of gaining the end result of all manufacturing.

Inspection Should Give Warning of Trouble

Management and industrial people outside the fold of inspection generally hold one of two more or less correct views concerning inspection. One is that it is the inspection department's job to sort, to cull out defective work. Another is that this department has the duty of constantly checking the flow of work to make sure that the work is not deviating from prescribed standards and tolerances and to give warning if it does. Without doubt the latter is the most valuable service inspection can perform in industry.

The question is frequently asked: If 100 per cent inspection is not 100 per cent effective, if a screening inspection is bound to miss some substandard pieces, how then can we be sure of getting defect free product through to our trade?

There is only one obvious but impractical solution: Don't manufacture any substandard, defective or out-of-tolerance product at all!

And right here is where patrol inspections fit. Properly performed, they can be a powerful agency toward preventing deviations.

But if the manufacturing department persists in making defectives in excess of a warrantable level, 100 per cent inspection or screening is the only recourse other than to deliberately foist contaminated product on the customer. With all its shortcomings and errors, 100 per cent inspection can and will clean most of the defectives out of a batch and at least help out a poor situation.

The most effective service inspection can offer industry, however, is some form of preventive therapy. It should expertly examine products and diagnose conditions at times and places where it can give warning that standards, specifications and tolerances are not being met, or are about to be exceeded, so that costly and wasteful amounts of substandard and defective products, parts and materials will not accumulate.

Sorting is a Lesser Function of Inspection

An accurate conception of the function of inspection decidedly divorces it from sorting. To use a simile, inspection

might be likened to examining an apple tree at the proper time for signs of larvae and disease, and spraying the tree, as compared to eternally working over the crop at the end of each season and throwing out the wormy fruit — which is sorting. Because inspectors are considered specialists in detecting substandard product they are, however, frequently given the 100 per cent inspection or sorting jobs.

In too many factories, screening or detailing is the only conception of inspection that is held. But if a plant is to secure the most valuable service from inspection and secure the greatest return from the investment in inspection, if an inspector is to really earn his salt, the inspection function and effort should be mostly located in the thick of production with a definite responsibility and ability for detecting, warning of and halting undesirable variations from established requirements and standards.

Patrol Inspection Should be Orderly

Efficient and effective patrol inspection is always orderly. Like a watchman, the patrol inspector makes his rounds and works on a schedule frequently as exacting as a railroad timetable. On his route he traverses a prescribed series of operations or machines or a mixture of both. Ordinarily his "territory" is so mapped out that he completes a round once every half-hour or once an hour.

Almost without exception, he makes his observations and reaches his decision by means of samples. Formerly, the size of sample taken and the results deduced from it were on a rule-of-thumb basis. Nowadays, more and more, the patrol inspector's sampling is being based on scientific statistical techniques. The matter of sample size and the decision to be reached from a sample will be given little specific attention here. More emphasis will be placed on the actual mechanics of patrol inspection. Most plants have their own systems, and the study of statistical quality control methods can give the inspector a more detailed description of sample sizes than space here permits.

Two Objectives in Patrol Inspection

In general, there are two objectives which patrol inspection may accomplish. Either or both may be aimed at, and this fact governs the size of sample and the way it is taken.

One objective is simply and directly to determine the con-

dition of the work which has been completed during some arbitrary period which has elapsed since the last patrol inspection visit. This is usually a half hour, an hour or so. Does the work conform to specifications or is there too great a percentage of defective units to permit passing it on to the next operation? This objective applies particularly where it is suspected that the operation may be erratic in performance. Patrol inspection sampling of this sort resembles batch inspection and a larger and more random sample is needed than when the second objective is, alone, aimed at.

The second objective is to determine the trend of the quality of the work being produced. Thus, from the standpoint of this objective, at any one visit by the patrol inspector, the work from a machine or operation is considered not only representative of the conformity of output (or lack of it) at that time, but is also descriptive of the output for some time past and indicative of how the work is expected to come off the machine for some period in the future.

With his eye on the second objective, the inspector is more interested in what the machine or operation is doing and will do, and is less concerned with the condition of the batch of work itself which has been produced since his last visit. He can reach an accurate enough conclusion with respect to this second objective by taking samples of the work as it comes off the machine, the number of pieces in this sample being less than was required for the first objective.

Restating these objectives it may be said that the first concerns itself with the acceptability of a lot prior to its transfer to another station for further processing. The second concerns itself primarily with an evaluation of the trend of the operation, that is whether or not it is producing and will continue to produce satisfactory pieces.

Interpreting Patrol Inspection Data

Suppose a patrol inspector's sample of work, where the blue print calls for 1.555 inch — 1.556 inch, shows the following five-piece reading:

1.5555
1.5553
1.5555
1.5554
1.5555

He could reasonably assume that for the past few minutes the machine had put out similar size work and that it would continue to do so. Also, considering that the size differences between the pieces he examined did not exceed .0002 inch, he could also reasonably assume the machine was inclined to be steady, to produce reasonably uniform work.

If at a second later visit he found the machine producing pieces that measured:

1.5556
1.5558
1.5557
1.5558
1.5559

he should then realize that the work done for some interval in the past was probably within tolerance but that very soon the machine could turn out some oversize work.

However, if his readings showed:

1.5552
1.5558
1.5554
1.5558
1.5553

he should suspect that the machine was not too capable of holding within the 1.555-inch — 1.556-inch tolerance and that there was a chance, with a .0006-inch size difference between specimens in his sample, the machine could have already made oversize work.

When patrol inspection is functioning as it should, the inspector is not only making an estimate of the condition of the work done since his last round, and passing judgment on it — making the decision, perhaps, that it is sufficiently contaminated to warrant segregation or withdrawal from the production flow for screening or salvaging, but he should be also sagaciously observing the trend or tendency of the work. It is just as important to warn of impending trouble as to report the presence of defective product.

The sort of judgment a patrol inspector must use frequently can be simply illustrated by considering the milling of a steel plate to blue print thickness requirements of .750 inch ± .005 inch. Such a specification technically permits the machinist to

make plates .745 inch up to .755 inch thick and still not be "breaking the law." However, it can be found out by both the inspector and the operator that the rough milled pieces are to be hardened and, afterward, surface ground to meet a final blue print specification of .745 inch ± .0005 inch.

The knowledge that the plates are to be hardened and surface ground to fairly fine tolerances may modify the inspector's judgment or decision at the milling machine. Suppose the milling machine operator is taking complete advantage of the .750 inch ± .005 inch tolerance and milling the parts .745 inch thick. This, then, would leave the surface grinder operator only .0005 inch in which to clean the surfaces flat and free from hardening scale and to overcome any taper or warping. Perhaps the inspector should consider such work unsatisfactory until official action had been taken to improve the dimensions and tolerances in a direction to avoid the dilemma implied above.

The judgment used at patrol inspection includes a little wider field than the literal, exact and technical comparison of products to the particular blue print or specification. The patrol inspector should have a thorough and accurate knowledge of just how and where a part is to be used and of the succeeding operations to be performed on it.

Visual Inspection on a Patrol Basis

Visual inspections are an important item in the patrol inspector's agenda. He usually must make decisions as to surface finish, tool marks, burrs and fillets. He must know, for instance, the effect that excess surface roughness in the parts he has sampled might have on the efficiency of subsequent machining operations on the same pieces. Or if they are not to be subjected to further finishing, what effect surface defects would have on the appearance of the finished, assembled products.

While the examples of a warning trend in dimensional changes offered above related to machined parts, the principle of inspection illustrated can be applied to almost any type of work. The detection of rubs, burnishes, tiny scratches, burrs or minute edge splits may well serve as warnings that a punch press die should be dressed, sharpened or adjusted. An examination of several units of soldered connections, showing, for example, tendencies toward carelessness or a cold

iron, could well indicate to the experienced eye certain timely corrections in the operator's technique which might prevent defective connections. Mispix just beginning to appear in the width of fabric being woven at a loom should be sufficient warning, even though the general appearance of the fabric is still commercially satisfactory.

An inspector should not be misled, he should not necessarily feel comfortably satisfied because his examination shows production to be within tolerances, specifications or standards. He must learn to read weather signs, to use a metaphor. All of which brings up the necessary point that the seasoned inspector knows nearly as much, if not more, about the production process as the operators or their supervision. It is primarily essential in inspection to be able to distinguish substandard material clearly from satisfactory product, but the patrol inspection, at least, is not offering full service unless it has the know-how to sense that the work is going out of line or soon will unless something about the process is remedied.

The Sample Should be Small

At patrol inspection the inspector is on his feet. The gaging and testing are normally performed at the machine though there are occasions where the sample is taken over to an inspection bench for special work or observation. The inspector uses as far as possible the same gages, testing apparatus and equipment the operator is using rather than special, duplicate or more precise inspection equipment. Hence his sample should be small and his work done as quickly as possible so as not to interfere more than necessary with the machine operator.

If the inspector feels that three or five pieces gives him information enough, he need sample no more; if he is in doubt, he should continue to examine enough pieces to make up his mind. Where the machine is multi-stationed, like a six spindle screw machine, for example, the sample taken should surely equal the number of stations or be a multiple of it — in the case of the six spindle machine a 6 or 12-piece sample, for instance.

The work done since the inspector's last visit may be found piled up on or near the machine or bench. It may be in tote boxes or pans, thrown into barrels, stacked on skids, or, as in

the case frequently of assembly operations, pushed along to the end of the bench. A great deal depends on the shop's material handling methods. The more modern shops have conveyor systems for taking away an operation's products.

Taking a few pieces as they fall from the machine will give the inspector an idea how the operation is going at the minute and also how the operation is likely to proceed for a while to come. But to make more certain of what the machine has been doing for some time past, the inspector will need to dig deeper into the pile. ("Digging deeper" in the case of conveyorized parts may be an impossibility of course, in which event the inspector must form his opinion from the production immediately at hand.) A good sample will represent as nearly as possible an honest cross section of the work already done between inspection visits and it should foretell to some degree the type of work that will be done until the next visit.

Errors in Patrol Sampling

Three errors are common in patrol inspection sampling. The inspector secures an inadequate sample — inadequate because the number of pieces is too few or because he failed to dig deep enough. Plain laziness is the most common cause of this error. Another mistake is due to a degree of overconscientiousness perhaps, or inexperience. The inspector spends unnecessary time on too large a sample. If the work were perfect, one piece would tell the story as accurately as a hundred. He should stop inspecting the minute he knows an operation is satisfactory, and probably will be, or that the work is rejectable and the operation should be stopped. The third type error appears when the sample includes pieces from work that has been previously sampled. Suppose an inspector approves an operation at nine o'clock, but by ten o'clock it is running just out of specification. If the inspector happens to scoop up already approved nine o'clock pieces among his ten o'clock sample, his judgment — his decision — can well be confused.

Use of Operator's Gages by Patrol Inspector

The inspector using an operator's own gages and apparatus, checking the work in the same manner the operator does, usually begets greater confidence in the inspection. For the patrol inspector to appear with his own micrometer, gages and apparatus (which are usually cleaner and shinier than

those on the machine) sometimes rouses resentment or suspicion, especially when, by unfortunate mischance, the inspector assumes some slight air of superiority.

The human relations situation just implied places at least one of two responsibilities on the patrol inspector. Where he is using the operator's gages or equipment to check conformance, he must be sure of their accuracy and reliability. After all, the inspector's basic responsibility is to compare, accurately, the product's conformance to specifications. The mere fact that an operator's micrometers say a piece is to size may not be sufficient. If the local circumstance is such that the inspector uses his own equipment, he must be sure above all else that it is accurate. It needs only one situation where the inspector's and operator's gages disagree and where the inspector's gage is the one in error to make the inspector's observations and decisions to some degree impotent from that time forward.

There are many occasions where it is impossible or unreasonable to have the operator's and inspector's apparatus absolutely alike in accuracy or calibration. In such circumstances, the inspector's equipment should be more tolerant. If an operator's gage would reject outside diameter at .374 inch, say, but the inspector's equipment rejected them at .373 inch, there is usually a job for the grievance committee brewing. Better to have the inspector's gage set at .3745 inch, if the specifications are .375 inch.

Performing Patrol Inspection Away From the Machine

Of course, a patrol inspection right at the machine can be a nuisance at times. There may not be adequate room for both the inspector and the operator at the machine itself or the production rate may be so rapid that the inspector's presence brings about unwarranted interference. In such a case, of course, the patrol inspector secures his sample and retires to one side to make the necessary checks with his own gages. For this purpose, the inspection department is usually assigned a convenient location in the manufacturing area with room enough for a bench, or benches, chairs or stools, a stand for a surface plate perhaps, and cabinet space in which to store inspection apparatus. Where the use of an optical projector, for instance, is prescribed, the instrument is usually located along with the other inspection equipment.

One reason for performing the inspection on sample pieces away from the machine is the fact that the particular test, observation or gaging may be considered a little too intricate or time consuming for the operator to do it. There is a point in manufacturing economics where it is less costly in the end to free the operator from certain inspections and have them completed by another man — by an inspector. A simple example appears in the sketch of the screw machine part in Fig. 3.

In this case the internal taper section was fairly critical, the tolerances so exacting that the use of a simple taper plug gage had been unsuccessful. The tapered cutting tool plus the machine setup could be depended on for a period. So a patrol

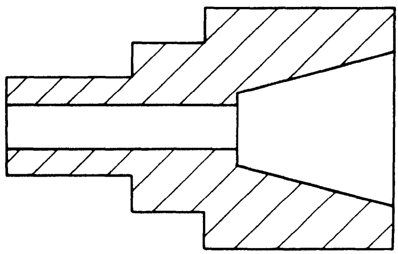


Fig. 3. It may be more economical to have an inspector check a piece-part, such as that shown, than to have it done by the machine operator.

inspector took periodic samples and checked the taper and depth to shoulder on a surface plate (see ball or disc method described on page 390). Incidentally, he made timely checks on new and resharpened taper tools, keeping a supply ready for the operator when the tool in use became dulled, as indicated by the periodic patrol inspection on the tapered parts being produced.

The inspection, the test to be made, may be too technical or even too hazardous for a machine operator to make. Refer to Fig. 14 in Chapter 17 concerning the test on diesel oil jets in a special fire and vapor proof booth, a test that basically checks some of the machining operations on the spray nozzles and a test that obviously could not be made at the lathe where the nozzles are turned and drilled.

Another example occurs at the automatic machine welding of chain links into lengths of chain. Every so often a sample of the chain lengths must be taken to a tensile strength

machine where the chains are literally torn apart. Such testing apparatus would be as space consuming in the welding line as an elephant.

A very simple example is checking surface roughness with the stylus of a surface recorder, an operation which would obviously take valuable production time and which should, of course, be performed in some location free from vibration and dirt.

There are many occasions among manufacturing operations where the particular inspection may not be made necessarily on the components — some occasions, for instance, where a drill jig might be checked rather than the pieces being drilled. The examination of a gear hob is another good example, or checking broaches or milling cutters.

Tracing Causes of Defective Work

Another function of patrol inspection is that of ferreting out causes of bad work. This is frequently the case on gang or sequence operations. If the pieces coming off a reaming operation do not conform, the basic trouble may actually lie in the previous drilling operation. Go back to Fig. 1 in Chapter 1 for a brief review of this possibility.

The trail back, many times, is not so obvious or simple. In one carpet mill, unreasonable variations in spun yarn thickness were traced back through miles of spinning and roving operations to unequal loading of raw wool hoppers on the far side of the first row of carding machines in the mill!

Another trial the patrol inspector faces is the disposition of parts which are defective because of some operation preceding the one he is inspecting, an earlier operation over which he has, perhaps, no jurisdiction. Suppose, as a simple example, an inspector is examining parts for plating, polishing and buffing defects and discovers a tray of them on which two countersunk holes are missing. Obviously the batch of parts slipped by the drilling operation way back down the line. (They may have been omitted by the vendor supplying the original parts!) The only thing the inspector can do is reject the parts, of course. But he must be sure the rejection is in no manner charged to the plating room even though some purist may argue that the polishers and buffers should have noticed the absent holes or that possibly he, the plating room inspector, should have been alert enough to have discovered

the omission long before the shop spent all the money on polishing, plating and buffing them!

Patrol Inspection of Continuous Processes

Patrol inspection includes checks on continuous processes. Figure 4 shows part of an extrusion insulation machine with a continuous gage measuring the over all diameter of the insulated wire. Readings at stated intervals are made by the patrol inspector at this gage, supplementing the more or less continuous observation of the insulating process by the operator.

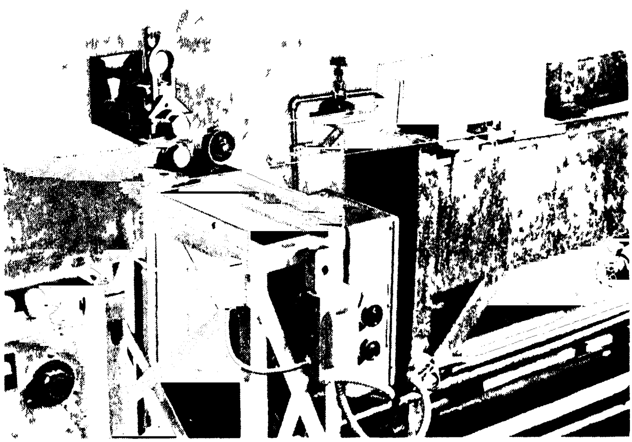


Fig. 4. Patrol inspection includes checks on continuous processes such as is taking place on the extrusion-insulation machine shown.

In a somewhat similar manner, patrol inspectors will frequently check temperature readings, make grain-size tests, chemical titrations, hardness tests and other inspections of a more or less strictly technical or laboratory nature.

First-piece Inspection

One common division of patrol inspection in machine shops is known as first-piece inspection or setup inspection. The names used practically describe it. It is not necessarily an inspection of absolutely the first part made, for the operator may spoil several pieces before his machine, tools or apparatus are properly adjusted, but it is the formal examination of the official first piece which the operator considers representative

of what he intends to do. The inspector may check a succession of "first-pieces," working along with the operator until both are assured the setup is satisfactory for continuous manufacture. Many times the inspection must cover checking the jig, tools or fixture.

The piece may be the result of several operations performed on it more or less simultaneously as in a screw machine, on a boring mill or at an assembly bench. Again, first-piece inspection might cover only a single operation.

Where the first-piece routine is practiced, the inspection is expected at the start of each new production order. In the case of continuous production, the formal first-piece check may be performed at the start of the day or shift and again perhaps at any time immediately after tools, equipment or the operator have been changed.

Requirements of First-piece Inspection

In some shops the operation is held up after the presentation of the official first piece until the inspection has been completed and the go ahead signal given. Usually, however, the operator proceeds, and stops his work for further adjustments if the inspection report is adverse. Either way, first-piece inspection should be prompt as well as thorough. The inspector needs to be available, timely and quick. First-piece inspection must be especially accurate and reliable in order to avoid any tendency on the part of the manufacturing department to place the responsibility for any subsequent bad work on the inspector.

The inspections are liable to vary in intricacy from a simple visual examination or the check of a dimension with micrometers to complex surface plate setups or the use of special gages, comparators and testing apparatus. The work can be better done, in many instances, right at the production operation. Time and effort are saved, many times, by checking a piece when, for example, it is clamped against the lathe face plate. Obviously also a machine bed weighing a ton cannot be readily shifted to an inspection station; the check up must be made on the floor. The operator and the inspector working together can develop mutual confidence in the outcome of the inspection. On other occasions, the parts are carried to an inspection station. The latter alternative has the merit of getting the inspector and the operator out of each other's way,

especially if space around the machine is at a premium. The inspector is then freer to do more precise work.

Objectives of First-piece Inspection

Most inspections are made simply to determine the bald fact that components do or do not conform to specifications. At first-piece inspection, however, the inspector should keep firmly in mind the important object of making sure the setup will very surely produce what is wanted.

As an example, the dimensions of a workpiece may correspond properly to blue print requirements but the inspector observes chatter marks, which are a symptom of something loose as well as a sign of impending out-of-tolerance work. The operator may hand him the first piece from a cylindrical grinder where the piece itself may be okay. But is there out-of-round? Is there taper? Have the countersunk center holes in the ends of the piece been properly lapped smooth? What provision is the operator taking for dressing the wheel and for properly sparking off? Is the coolant flowing rapidly enough? Is it the right coolant at the right temperature? Is the machine in the line of direct sunlight or drafts? Some of these questions may seem foolish but not too zany for .0001-inch tolerances. If first-piece inspection is to be worth the time spent at it, more than just the bare conformance to specifications must be observed.

One object of first-piece inspection is for the inspector to observe finish, appearance and workmanship. If the first piece does not conform to the general shop standards for surface finish, tool marks and chatter, correction should be made. Perhaps the stock is not "cleaning up." Where the first piece involves a threading operation, for instance, the thread form should be examined. In the case of a tapped hole, perhaps the chips are not clearing out properly.

In many operations, especially at boring mills and similar machines, the primary function of a first-piece inspection is to check layout. The inspection may be a first-class, lengthy surface-plate problem on hole location. Angles and tapers may require a sine-bar setup. Along with location, on some types of components, it is up to the first-piece inspector to remember to check concentricity; or squareness; or parallelism.

First-piece inspection is especially useful in the departments where stamping, punch press and draw press parts are made.

Duplication of parts is very nearly achieved on punch and die work. In addition, press work proceeds usually at a rapid pace. Hence, if first-piece inspection confirms the setup, an undue amount of unintended scrap may be avoided as well as a series of subsequent checking inspections. Some shops, in fact, rely on the first-piece inspection and a *last-piece* inspection for press work, thus eliminating intermediate patrol inspection, on the theory that if the first and last pieces conform, all the work in the batch between should be satisfactory.

Visual Examinations in First-piece Inspection

First-piece inspection of press parts should include examinations for certain unsatisfactory conditions other than purely dimensional conformance. This can be illustrated by reference to the part shown in Fig. 5. The size, alignment, setting and

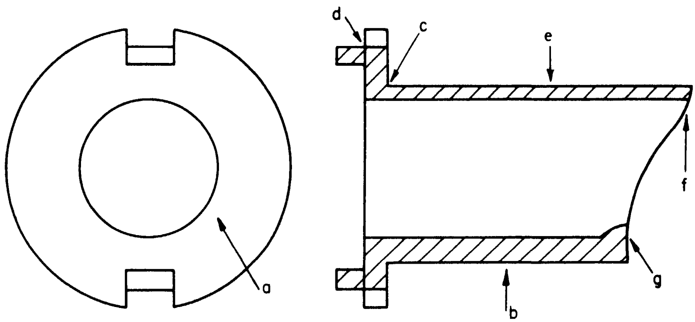


Fig. 5. First piece inspection of press parts should include an examination for unsatisfactory conditions other than purely dimensional conformity.

adjustment of the punch, dies and tools may spoil the pieces for some of the following reasons.

If the corner of the die or punch has been machined too sharply or if the punch shoulder travels too close to the die, the flange, *a*, is formed too square. Wrinkles or corrugations are sometimes indicators. A fatigue crack or split may be started at the corner *c*. One test is to clamp the flange in a vise and attempt to tear the body away from it with pliers or a bar.

Similarly, the tear test should be used to discover fatigue cracks at the corners of the lugs at *d*. Splits are ordinarily discernible to the eye, but the tear test is perhaps more reliable.

If the punch and die are not aligned, if either is egg shaped, a thin wall, as at *e*, can result. The visual evidence is a series of parallel streaks of rubbed or burnished metal, called die marks, and, frequently, a sag or elongated lip formed on the thin side by the squeezed metal as at *f*.

The end of a punch may be nicked or chipped a trifle. The trouble can be diagnosed from the appearance of a "fill" or "plug" as at *g*.

Deep scratches along the inside or the outside of the body, *b*, indicate sharp burrs on the punch or die, respectively, or the presence of dirt, metal or grit particles.

Foundry Inspection

A whole book could be readily written if all the intricacies, technologies and specialties of foundry work inspection itself were to be described in detail. Perhaps, however, a few suggestions can be capsuled here.

One thing is immediately apparent to an inspector first undertaking the inspection of foundry products in the foundry: it is no place for an ignoramus. Even an intimate knowledge of foundry practice fails to answer many questions that come up. Probably the best schooling for an inspector is as a worker right on the floor.

A large part of foundry inspection is of course visual. Castings must be examined for blowholes, pits, blisters, scale, inclusions, glaze, cold shots, parting fins, excess gates, improper snagging, cores not adequately cleaned out, no cores, broken cores, shrinks, short pours, poor mold, broken and cracked castings, just to name a few of the possibilities.

The usual time and place to make inspections on castings is after they have been cleaned, snagged, sand blasted, after all routine foundry finishing operations have been performed on them and they are ready to be shipped out of the foundry.

A foundry inspector needs a pretty thorough knowledge of where the castings are to be used and all of the operations, strains and uses they might be put to. Taking blow holes in valve bodies as an example, a blow hole on the outside of the casting would spoil its appearance as an article of merchandise though it might have no effect whatsoever on the satisfactory operation or service of the valve. On the other hand, blow holes in the interior of the valve might be overlooked so far as appearance is concerned but if they are too deep, too

frequent or cover too much area, they might well have weakened the structure of the valve and be the start of the complete fracture of the valve body under the 1000 pounds per square inch hydrostatic test. Blow holes appearing on surfaces that are to be machined are of little consequence except when their depth or area will not "clean up."

In practically no other industrial area is the question of standards such a moot one. How much of a blow hole or pit is allowable? Just when is a misplaced core sufficiently misplaced? What is careless snagging? Was a gate so broken off it left a crater and robbed needed metal from the body of the casting?

Measuring in Foundry Inspection

Measurements on finished castings are important and a pair of calipers and a steel rule (plus sometimes a steel tape)

Fig. 6. For foundry work, indicating caliper equipment to measure sections accurately and quickly is usually required.

are routine equipment for the foundry inspector. Many castings (and patterns and core boxes) cannot be adequately checked without a standard surface plate and height gage setup although tolerances are usually not closer than 1/64 inch. Indicating caliper equipment for measuring sections accurately and quickly is shown in Fig. 6.

One of the major reasons for measurement checks is to be sure there is enough metal in the right places so that castings will machine and clean up properly. Thin webs and sections break through, or weaken the casting structure so that the casting crumbles under stress in final use. Too much metal in the wrong place simply makes unnecessary machining and cutting later. The diagrammatic sections in Fig. 7 are offered as a simple example of what is meant.

Suppose the casting is to be machined as sketch A in Fig. 7 indicates, with shoulders at *b* and *c* and surfaces *f* to be milled smooth so that dimensions *d* are valid. Suppose also two holes, *a*, are to be drilled in the casting. Now suppose the casting

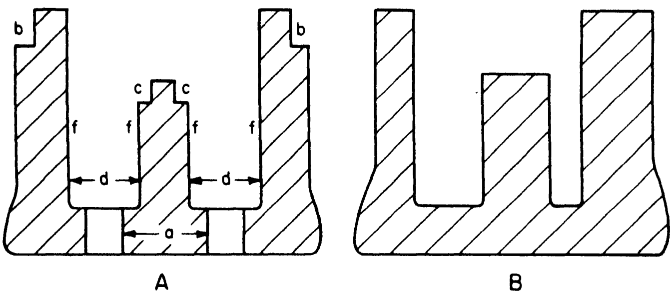


Fig. 7. If a casting comes out of the mold somewhat in the shape indicated in (B) it cannot be finish machined to the dimensions shown in (A).

comes out of the mold somewhat in the shape section B suggests. If nothing else, it is obvious one of the two holes, *a*, would have no place to go at the drilling operation. It is also obvious the shoulder *b* could not be milled on one web and that much more metal than is economically needed would have to be taken off of other webs.

Discovering Faults That are Not Visible

All casting flaws cannot be observed in ordinary external visual inspection. If blow holes show on the surface there are just as liable to be voids under the surface. Cracks, inclusions, cold spots, crystallization and other structural weakening flaws occur way down in the centers of casting sections, conditions which, of course, are permanently sealed off from the sight of the naked eye.

Sometimes clean castings can be tapped with a sledge and if they don't "ring" true, the presence of some degree of

internal flaw may be suspected. A number of plants have gone to the expense of installing X-ray apparatus with which the interiors of metal sections can be peered into in much the same way a doctor can examine human "innards."

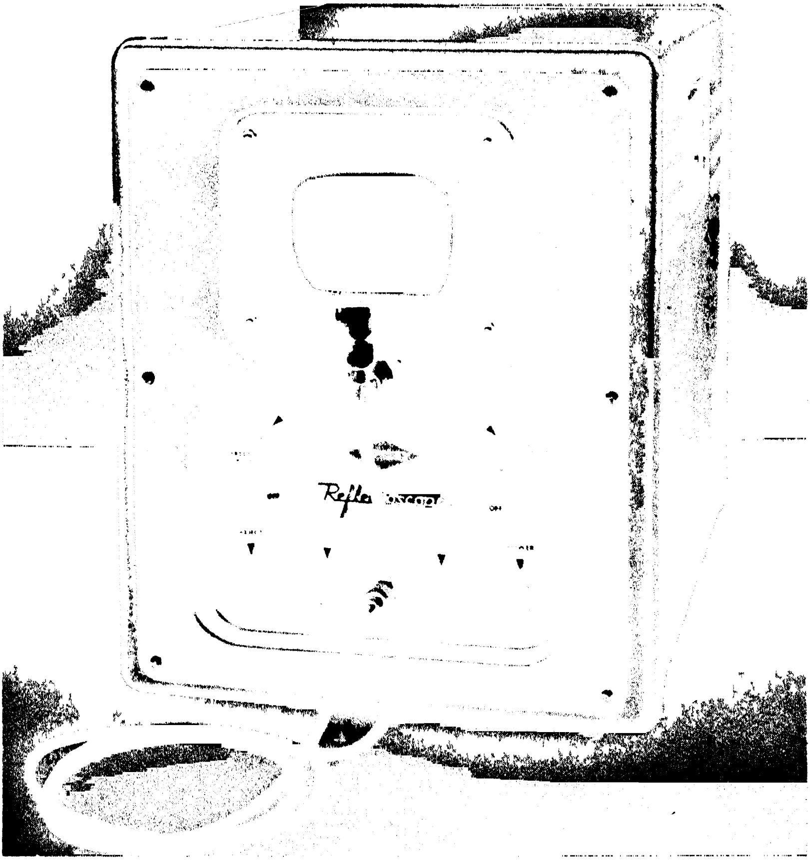


Fig. 8. One type of inspection equipment which by electro-mechanical means locates flaws in a piece of metal.

More recently there has been developed so-called supersonic equipment of the sort illustrated in Fig. 8. Basically this equipment, through a crystal, sets up extremely high frequency vibrations in a casting when the crystal is placed against it. These vibrations sweep through the metal section, their traverse being made visible on an oscilloscope screen. If the oscil-

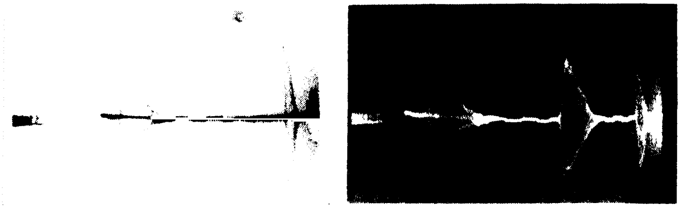


Fig. 9. (A) An oscilloscope pattern which has been recorded from the apparatus shown in Fig. 8. This pattern indicates the material to be flawless. (B) This pattern indicates a flaw in the material.

loscope pattern shows "clean," as indicated in Fig. 9-A, there is no flaw in the metal, at least within the vibration area or range of the existing location of the crystal searching unit. Where there is a flaw, it registers on the oscilloscope as in Fig. 9-B. Of course, all sections of a casting can be explored by moving the crystal unit from place to place and observing the oscilloscope. Incidentally, this sort of equipment is useful on welded joints, rolled sheet metal, forgings and rolled bar stock. Figure 10 shows the equipment being used to check locomotive wheel castings.

Another type of detecting equipment employs a metallic powder which is sprinkled on the casting surface. The equipment then magnetizes the casting, or sets up a magnetic field

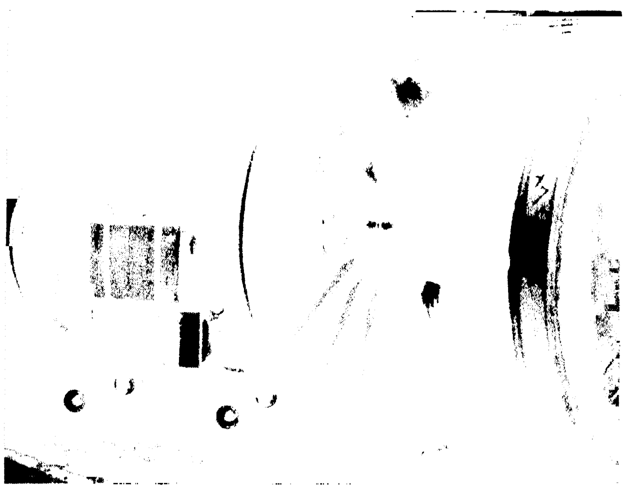


Fig. 10. Equipment of the type shown in Fig. 8 being used to check locomotive wheel castings.

in which the powder shows the pattern of the lines of magnetic flux. Surface cracks and flaws to some depth under the surface interrupt and distort the regular magnetic flux pattern and thus disclose themselves.

As has been intimated, only a few high lights of foundry inspection are being discussed here because foundry work is so much a specialty. New developments in the hands of metallurgists and experienced foundry artisans are appearing every day. The inspector can well be expected to take pyrometer readings, to help in chemical analyses of metals and in other metallurgical routines. Tensile, crush, abrasion, specific gravity and other tests may fall into his routine. Until he can qualify somewhat as an expert, the thing for the inspector to do is to follow religiously the instructions for tests given him by the engineers and metallurgists.

Receiving Inspection

Again, a whole chapter, if not a whole book, could be devoted to *incoming acceptance* or *receiving inspection* and, again, space will be used here only to emphasize a few salient principles of this particular kind of inspection. The "Incoming" inspector is a specialist to say the least and in an incoming inspection department there may be a variety of specialists. Consider receiving inspection at, say, an automobile plant where inspection runs the gamut of bumpers, glass, electric cable, spark plugs, tires, screws, bolts and nuts galore, upholstery fabric, gears, sheet metal, oil filters, generators, plastic knobs, gaskets, light bulbs, switches, locks, clocks, springs . . . to tick off a miscellaneous scattering of the horde of items to be checked in one fashion or another.

To discuss particular receiving inspection procedures in a book of this sort would be misleading because in one plant an "incoming" specialty may be lumber, in another, rod and sheet, in a third, tank cars of a chemical. In one shop attention may be paid to quantities of screw machine or press parts and its next door neighbor may be concerned with timing mechanisms or condensers. The checking of newly bought cutters and tools is frequently an inspection department responsibility.

Receiving inspection, of course, deals with purchased parts, subassemblies, materials and goods coming in from outside the shop. Orders and contracts are placed with other manufacturers, subcontractors, suppliers, jobbers and merchants for

the various things the shop needs that it does not make itself but that either enter the manufactured product, are supplied with it, or supplement the manufacturing process. If the factory is one of a series owned or controlled by the same company, receiving inspection may entail the acceptance of parts, sub-assemblies, materials and work from other branches.

As a general thing, receiving inspection is performed in an area close by the factory receiving department if not actually in it. In the larger plants incoming inspection is a separate division and function of the inspection department and the factory's materials handling routine definitely includes the step of receiving inspection. Usually, too, the inspectors assigned to incoming inspection carry on no other inspection work. In the smaller shops, the division is not so sharp. There may not be enough receiving inspection but what properly trained inspectors can be shifted over for a part of each day or week to clean up the accrued receiving work and then be returned to other routine inspections.

Functions of Receiving Inspection

The primary concern of the receiving department itself of course is to get the count, weight, volume, etc., of the goods, to check bills of lading and make the necessary records, all leading to paying the company's invoices.

Another receiving department activity is frequently connected with the fact that purchased materials arrive packed in more or less unwieldy units. The goods must be rearranged in other containers or in such a manner that they can be handled more conveniently on the local conveyors or trucks or in the local stock rooms. Such activity gives receiving inspection, if it is on the job, a better chance to sample many times.

The conclusions arrived at by receiving inspection are based most usually on samples and seldom on 100 per cent inspections. And nowadays the sampling itself is usually based on one of the available scientific, quality control sampling tables.

Random Samples are Needed

All of which puts up to the receiving inspector the strict necessity for obtaining truly random samples. Since the goods to be inspected may be baled or boxed, packed in barrels or bags, or arrive on pallets, in rolls or reels, or in bundles, the inspector frequently faces a mechanical task of getting a

satisfactory sample of each item. In fact, securing the required sample may take more in time and energy than the actual inspection. Because it is burdensome, however, it should not be neglected.

The next question, of course, is whether or not the goods conform to specifications.

The Purchase Order as a Specification

Almost without exception, the purchase order is chapter and verse as far as specifications are concerned. The term "purchase order" is used here in the broader sense, for the goods may come in as the result of a telegram, verbal order or a lengthy contract. Parts received from a branch office arrive in response to some interfactory memorandum like a material requisition or production control order.

The purchase order may contain a complete description — the specifications — on the face of the order itself. Customarily however, it is accompanied by blue prints or special written specifications. Again, reference will be made to a supplier's catalogue number or to some universal commercial standard like, say, S.A.E. specification number 1010 for a particular composition of carbon steel.

Check the Purchase Order Carefully

The point to be emphasized is that the inspector, as the first step in preparation for the receiving inspection of any article, should refer to the purchase order (or dig out its equivalent if the order was verbal, wired or in the form of a contract) and carefully study all blue prints, sketches, written specifications or catalogue references in connection with it. The usual danger at receiving inspection is over-confidence — the inspector believes he knows more about the specifications than is actually the fact. Particularly at receiving inspection, he should watch out for changes in the purchase orders or specifications. Usually the receipt of the same kind of parts or materials is not a daily routine. Several days, weeks or even months may elapse before another shipment of a particular sort of goods shows up. In the meantime, the inspector could well have forgotten details of the specification or the engineering department may have made a slight but important change. Look up the purchase order each time.

The expression "look up the purchase order each time" is also used in the broader sense. The act of looking up may

involve securing specific information from the laboratory or engineering department or a discussion with the manufacturing department regarding their problems in connection with the particular material or components at hand. Sometimes the exact information desired in order to reach a decision at receiving inspection must come from the sales department itself. At any rate, the receiving inspector should be equipped with the latest blue print or set of specifications if they are at all available. Some care has been used to emphasize the preparedness implied in the paragraph or two above because, on the whole, the receiving inspector examines parts, materials or goods that are to various degrees unlike anything made in his own shop.

Learn How Items Inspected are Made and Used

The next step in preparation for receiving inspection is to know fully where and how the parts, goods or materials are to be used in the shop. Specifications at best are limited in the details they can describe and the inspector's complete knowledge of his shop's manufacturing processes enables him to use better judgment in the acceptance or rejection of a vendor's order. For example, he might be tempted to reject porcelain insulators because they are discolored when a knowledge of their use would instruct him that chipped, cracked or crazed porcelain is the legitimate basis for rejection.

In addition to precise knowledge as to just how each received item is used on or with the products made in his own factory, the inspector should seize every opportunity to learn how the parts, products and materials are made in the vendors' plants. Discussions with his own engineers and purchasing agent may give him valuable pointers. He may be able to arrange contact with vendors' representatives for the same purpose. Modern plants deliberately, wisely, arrange for members of the receiving inspection force to visit some vendors' factories.

There is nothing that rejects so arbitrarily and blindly as ignorance. An untutored inspector may unwittingly accept unsatisfactory goods but there is some question as to whether that is worse for his company than to ignorantly reject material unfairly. Rejections cost money in shipping charges, correspondence, rehandling, and a dozen other ways including debit memos, statements and a multitude of bookkeeping oper-

ations. The peculiarity about it, which many inspectors fail to think about, is that, in the end, unwarranted rejections cost the vendor nothing. No, the inspector's own company pays for his folly because in one fashion or another, usually in price, the vendor charges the unnecessary expense back.

The only way the inspector can equitably accept products at receiving inspection or correctly, fairly reject them, is to *know* what he is doing and any step he can take to add to his knowledge in regard to any item makes him that much more valuable to his own plant.

Make a Full Record of Each Receiving Inspection

One other step, on top of making technically accurate inspections, which the inspector should surely take is to make an accurate and comprehensive record in connection with each receiving transaction. His written-down data or report should include his own plant's purchase order number, receiving slip number and any other identifying information; the vendor's name and any order numbers the vendor uses; the date and time, of course; the count, weight or physical inventory of the lot, batch or order sampled; the sample sizes used, the count of defectives or a record of the basis for acceptance or rejection, and at least a brief note as to the technical reasons for rejection. Sometimes a sample piece typical of the rejection is retained for a while.

Two kinds of disputes may arise from the results of receiving inspection. The arguments may come up three days later or three months later. (In Government renegotiation cases, some individual differences have been aired more than three years after the original transaction.) The inspector's own shop may sharply disagree with his acceptance of certain materials or parts. Or, many times, the vendor may object to his rejection. Either way, the inspector needs all the facts, records and evidence he can command to illustrate and justify his decision. Receiving inspection records have proven valuable many times in legal suits.

As a detail in making receiving inspections and records, the inspector should carefully distinguish between original vendor manufacturing defectiveness and damage or defectiveness caused by packing, shipping, receiving and careless handling. He may rightfully report critically on the way the goods were packed or handled, he may express an opinion as to whether

the damage was done by the vendor's handlers and packers, by transportation agencies or in his own receiving department.

Examples of Receiving Inspection

As an example of some of the details in receiving inspection, Fig. 11 is offered to illustrate first and primarily the taking of a sample. The item under inspection is a shipment of studs for aircraft equipment. Note that each of the cartons has been opened and a small but random sample from each box has been set out on the inspector's bench — all the groups adding up to a random sample of the shipment. Notice, too, the punch-board style tray in which any defective pieces found are de-

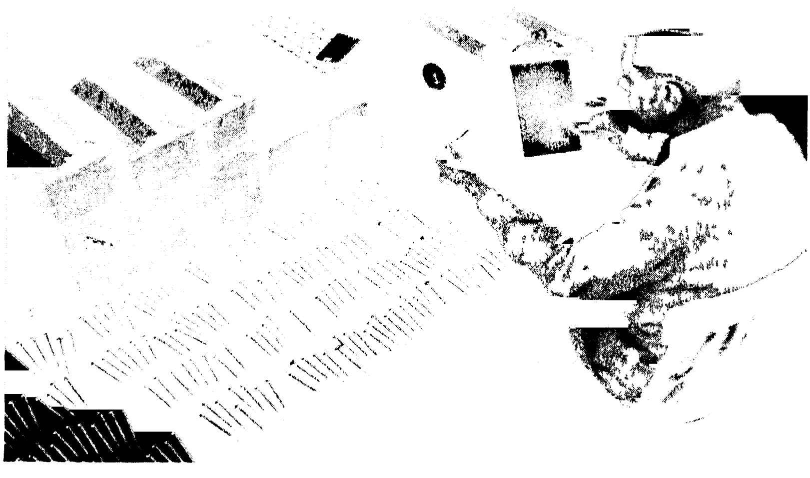


Fig. 11. In receiving-inspection procedure, a small random sample lot is taken from each of the packages received, all of the lots adding up to a random sample of the shipment.

posited. At the moment, in Fig. 11, the inspector is making a permanent record of his sampling in the modern form of a quality control "lot plot" of the characteristic of pitch diameter.

As a further example of the diversity of inspection technology met in receiving inspection, consider some of the items sampled, inspected and tested in a factory manufacturing household electric appliances.

This factory is a large buyer, of course, of electric cord in coils and reels. One of the receiving inspector's decisions to be made concerns the appearance of the braid, the outside cover of the cord, an important factor because the appearance of the extension cord on each electric appliance has some effect on its merchandiseability and its retail price. Is the braid tightly or loosely woven? Or so loosely woven it will readily scuff apart at assembly, say, or on the dealer's counter?

Little electric switches are bought. Just a few specimens from each incoming batch are connected up into a special motor driven gadget which clicks them on and off so rapidly that they are given the equivalent of ten years normal use in a few hours. At the same time they are "loaded" with twice the normal amperage and ten times the normal voltage. All to be sure they will withstand not only mechanical wear but also electrical arcing.

Such a test is known as a test of extra severity. No one switch would probably ever have to endure such extreme treatment. The theory of a test of extra severity is that if the product passes through *it* successfully it will stand up under the treatment it will normally get.

Another receiving inspection job in the electric appliance factory is checking sheet and strip metal and rod stock. In addition to dimensional and one or two metallurgical checks, the inspector has two other conditions to look out for. The sheet comes in as steel, stainless steel and aluminum; the rod as steel, stainless, brass, and copper clad. If the mill, the metals jobber or even the inspector's own receiving department have been at all careless, it is easy for stainless steel and ordinary steel to become mixed, or stainless steel and aluminum alloy sheet. The inspector must be alert to these mixups which are absurdly easy for handlers to cause. The other special condition is the matter of visual examination of some types of sheets for cuts, pits, nicks, scratches, roll marks and corrugations — the several sorts of inherent blemishes which, when the sheet is rolled or pressed into final form, would spoil the exterior appearance of the electric appliances.

Other unusual incoming inspection observations include high-speed centrifugal runs of commutators designed to unseat copper segments under extra severe conditions, bursting or rupture tests on sheet fibre, temperature readings on the

melting points of pressure safety plugs and bending tests on copper connecting lugs. In addition to these, there are more nominal dimensional checks on a variety of die castings and plastic parts.

Good receiving inspectors are better chosen from the ranks of shop inspectors who have had at least some months experience as patrol, batch, and 100 per cent inspectors. They should have had considerable practice with gages and instruments. For them to have served stints in the plant's assembly lines, the repair department, in the laboratory, as well as along the machine lines, represents worth-while experience for receiving inspection work. Even then, the receiving inspector must study, learn and observe. If the plant is at all progressive, something new and unusual to be inspected and checked is continually coming in the receiving door.

CHAPTER 19

Hints for Making a Good Job Better

An inspector's responsibility does not end with having made certain measurements and observations and having formally accepted or rejected work. Unlike many other shop operatives, he is usually called on to make reasonably detailed records of his transactions in some form.

Practically every factory maintains an order routine, part or material number system, production records, time, cost and scrap tickets, routing or operation sheets or, from simple to intricate, some form of the manufacturing bookkeeping now usually known as production control. What the inspection department does about parts, goods and materials in the process chain can have an important effect on the production control results and as a consequence the inspector performs some or much of the routine accounting.

While practically all factory paper systems seem to have a common denominator, there are perhaps as many different shapes, forms, types and details of tags, route sheets, cards, order forms and what not as there are industrial plants or individuals in them. A brief discussion, like this section, might show samples of a very, very few of the tremendous variety of forms in use but there is a question whether the reader would gain enough information to be of practical use to him.

Items That Should be Recorded by Inspector

Sticking simply to principles and slanting the discussion to the requirements of an inspector, there are several items of information in connection with almost any inspection that an inspector should make note of regardless of the particular form layout in his shop on which such information is to be pencilled.

The particular factory or production control order number should be recorded. This might be termed a lot or batch number. The part number or numbers, the material or assembly

number should be noted too. Such items as the building and manufacturing department symbol, the machine or apparatus number, the operator's name or number are valuable information on any inspection record. A memorandum of the particular operation should be made, like annealing, cut-off, drill two saddle holes, or operation number 46-A if the process follows a numbered operation sheet.

Never forget the date on any tag, form, report or memorandum of course. It is also good practice to note the time of day of the inspection.

Peculiar to the inspection department's responsibility of making manufacturing records is the question of sample size. On patrol inspection reports, for example, there should appear some note of the size of the sample from which a decision was reached regarding the disposition of the work or necessary readjustment of the machine or process. The same rule applies, of course, at batch inspections, final inspections and at special tests. Where the inspection routine completely covers the matter of sample sizes with the use of known sampling tables, the record of the sample size may not be so relevant, but even then, the memorandum of it is frequently handy. For 100 per cent inspections the inspector can write down the sample size as 100 per cent or use the word "all".

Connected with the matter of sample size in an inspector's particular record is the count of defectives found. The decision to accept, reject or modify the procedure is based not only on the sample size but also on the count of defectives uncovered.

Finally, an inspector should always make some sort of memorandum concerning the disposition of the goods, wherever he enters the production flow. If he accepts or "passes" the work, it is assumed that the goods proceeded along established channels, but many situations arise where the record of such an event proves useful. The time, for instance, at which a certain lot passed a certain point in the process is frequently valuable. And exactly what happened to the goods where a rejection was made is of course an essential record.

There should be few or no occasions where the inspector would not validate his report, record, memorandum or recommendation by signing his name or initials. "Whodunit," especially in the case of an inspector's rejecting goods, is a question frequently asked in a factory.

In most plants, the inspection department has its own tags or forms, usually in color — red, yellow, blue, green, etc. — which call the attention of everyone concerned to the inspection activity.

The above can perhaps be recapitulated in the following form.

Date......................

Time	Description of parts materials or goods	s.s.	d.	Disposition

Signature..............................

(In the above form "s.s." stands for sample size and "d" for the count of defectives.)

Whatever routine factory forms are furnished the inspector and whatever details of information they demand, the inspector should see that the above information somehow appears on any reports he pencils, even though the shop tag does not specifically call for one or the other items.

Personal Records of Inspector Useful in Case of Controversy

A personal notebook is a legitimate part of an inspector's equipment. There are many situations where he will find it handy if not life saving if he has maintained some sort of a log or journal of his activities. Such a diary should include in each case many such items as location, department, machine number, operator, part number, time and date.

The inspector's personal record should show the disposition of the goods inspected, in each instance, whether they were rejected or accepted, along with a brief note as to where the material was sent if it was taken out of the normal production flow. Sometimes, as a matter of self defense, the inspector will jot down a note or two concerning a discussion (or wrangle) over the rejection of a lot or the shutting down of a machine.

His note book, too, is a good place in which to write down special instructions received from his supervision or general shop or engineering orders.

Very often an inspector is called on to justify a rejection. The production or engineering department may ask him why. He may be called into a salvage committee meeting. Sometimes his judgment in accepting a lot or letting an operation proceed is questioned. A report, in other words, concerning the conditions observed during manufacturing is pretty much a part of the inspector's routine and responsibility.

Where he patrols machine after machine or examines lot after lot of parts during the course of a day, it is difficult to remember the details accurately or, frequently, to distinguish in his own memory one lot from another. Once work is accepted or rejected, it fades from his mind. To aggravate the condition implied, questions about the condition of work or the reasons for rejections come up several hours, if not several days, later.

Rather complete records made by a receiving inspector have been found very useful in disputes with vendors over goods returned. Sometimes credits are not issued or bills are left unpaid. Original receiving inspection records, in fact, have been accepted as substantial legal evidence in court cases.

Keeping track of time and of lot numbers, machine numbers and other descriptive data is important because discussions and disputes arise many times over the wrong group of work. It might be valuable to know, for instance, and to say, that the work coming from a certain operation (all having the same lot or order number) was satisfactory until about 10 A.M. of a certain day, that subsequent work was defective and rejected, and that the trouble was not cleared up until about noon.

To be able, in addition to accepting and rejecting work accurately and assaying the cause of trouble intelligently, to report comprehensively at some future time, concerning the whole situation enhances the inspector's position and reputation in the shop very materially.

Budgeting Time Helps Inspector Keep Ahead

A discussion of reports and records intimates system and certainly little is so profligate of time as an unsystematic inspection routine. Aside, perhaps, from all day, repetitive,

100 per cent inspections, most inspection is subjected to a series of interruptions and distractions, many of which seem more pleasant and more important than the dull grind of plain inspection operations. Just a little lack of attention, concentration, direction and self-discipline and an inspector will find himself going about his job like a hound pup ricocheting across a meadow trying to catch up with every scent his nose whiffs.

One reason for the difficulty just implied, especially in the case of the patrol inspector, is that his normal effort takes him over a more or less extended area of the factory. He comes in contact with a diversity of humans, equipment, goods and problems. He is not tied to a machine or a small area like an operator; his attention is not necessarily concentrated on getting out so many pieces or yards or other units per hour. To a considerable degree, he is independent in action; he seldom has someone whose work and activity he is directly responsible for and, usually, his own supervision is seldom breathing down his neck. It is usually a little bit easier for him to think of some reason to go back to the office, or his route takes him naturally by the candy machine or smoking area. All such factors make self-discipline preemptive in the case of an inspector.

The amount of work generally delegated to an inspector makes time his enemy. If he doesn't watch out he will find himself never caught up. Aside from the sort of distractions implied in the paragraph above there are frequent legitimate interruptions. He may conscientiously plan to oversee the work at ten machines in the succeeding hour, or to finish the sampling and screening of the batches delivered to his bench, only to be held up by some unforeseen but necessary reinspection, by the need for calibrating a gage, for instance, to hunt up a missing blueprint, perhaps, or even to be forced to stop and wrangle over a rejection with a supervisor or engineer.

It is useless for the average inspector to delude himself that his schedule will go along as he has planned it. Far better that he deliberately allow time for potential interruptions, delays and traffic jams.

Hence the importance of odd moments. As an example, suppose he completes a round of operations or the inspection of a batch sooner than he anticipated. The ten minutes or so gained, say, he might well use to check his micrometers, clean

and oil gage blocks, master a comparator or fill out a report. In previous chapters, mention has been made of carefully putting gages and apparatus away in such a manner they are completely ready for the next use. Work of this miscellaneous character should not be left to that hoped-for free hour.

One of the reasons a personal "log" was mentioned above was to bring out on paper so that they could be studied the reasons why an inspection job may be continually lagging behind. It is just as essential for an inspector to analyze his routine and cut out the irrelevant as it is for the successful salesman or the busy executive "up front."

Most of the foregoing is in the nature of warnings. The inspector is urged to plan his schedule constructively each day, and for each hour, ahead of time to the best advantage he can under his working circumstances. All through this book orderliness, system, arrangement, "make-ready" and "put-away" have been stressed in connection with practically every individual operation and technique. The same spirit should dwell over an ordering of a whole day's work.

A Little Psychology Makes the Job Go Easier

It is said a policeman never meets or talks to a mentally normal person. Recall how you feel when you find a uniformed officer at the door and the relief you sense when he's only there to sell you tickets to the policeman's ball. It is also said a salesman likewise never deals with a prospect mentally at ease. Let even a friend of yours approach you about buying insurance, bonds or a new car and your mind stiffens, your resistance mounts and even your suspicions are aroused.

And in the progress of his business the inspector faces abnormal mental resistance situations. For one thing, whether he wants or intends to or not, the inspector is more or less in fact criticizing someone. Or the worker or supervisor he is about to report to in connection with the work suspects he will criticize. Another thing has been said — you can belittle a man's ancestors, his dog, home or car, and if you do it good naturedly he will laugh with you. But if you criticize his work or imply he doesn't know how to do his job, trouble is brewing. So an inspector should develop and possess some of the attributes of the diplomat. In his case friendliness and firmness should go together.

To help materially in the sort of situations just implied, the

inspector must, it can be seen, be very careful with his measurements and inspections, he must be positively correct in his conclusions and decisions. If the inspector is right, the other party has little comeback even though he is angry. The other party can be angry only at himself.

The worst attitude a patrol inspector can take is that of looking for every chance he can find to reject work and shut down machines. His job is not like a traffic cop out with a batch of parking tickets. Another very disagreeable personality trait to display is for an inspector to appear sanctimonious. He should be sincerely searching for every opportunity to approve the work, he should be earnestly hoping for acceptable work, though of course, basically his job is hunting for trouble. But there are ways of going at this unpopular assignment that take the sting out of rejections. Claim agents, salesmen, doctors, many of them, have learned how to sugar coat the necessarily unpleasant.

As a matter of organization in the average plant, the inspector who does reject work, justifiably, should try to follow organization lines. Theoretically, at least, it is not his prerogative to reject the work to the operator who made it; notice of the rejection belongs to the foreman or supervisor of the area and it is essentially the latter's duty to notify the worker of the trouble and take steps with him to prevent a recurrence of it. Essentially, too, a man cannot serve two masters and the inspector should not assume any of the prerogatives of the production operator's supervision except by express permission and arrangement which the worker understands.

As for his own psychology, to use an expression, an inspector had better build and cheerfully maintain a mental bulwark against one condition which is of rather common occurrence. An inspector's decisions are frequently overruled by those in higher authority, sometime of necessity and on other occasions, alas, from mere personal whim. An inspector new at the job frequently has his findings changed for him because he has not yet fully comprehended all the details of his work, because he is inexperienced.

To any man of spirit, it is a little bit difficult to have very carefully inspected and gaged, to have thoroughly checked and rechecked, before rejecting a batch of work and then to have a superior come along (frequently and usually because

production supervision has protested the inspection decision) and countermand the rejection. The repetition of such incidents can mean almost complete frustration to the inspector. If such reversals are made unpleasantly and arbitrarily, the inspector also loses face.

There are frequent extenuating circumstances in industry where overruling an inspector cannot be avoided. The absolute need for the goods in order to maintain subsequent orderly production or to meet stringent shipping schedules can require the movement of the goods even though they contain a high proportion of substandard units. Sometimes engineers and manufacturing people can see ways unknown to the inspector of salvaging a rejected lot or modifying some subsequent production operation to accommodate the substandard work and the rejection order is reversed.

In the face of continuing situations of the sort implied, the inspector must never yield to frustration or assume a shrug-shoulder, resigned, indifferent attitude. He must avoid the danger of slackening the standards in spite of repeated assaults on them by others. Most of all, where local circumstances seem to make reversals of his decisions frequently necessary, he must not start to approach his inspections in the frame of mind that his decisions are going to be overruled no matter how intelligent they are. It is almost impossible to make continuing impartial, objective inspections in an atmosphere of apprehension. An inspector can let himself slide into the ultimate position of reaching no conclusions at all but always waiting for some one higher to make each decision. Such a mental attitude is one of the sign posts on "skid row." So past history must be washed off the slate and each inspection, each decision, made without the bias or influence that previous reversals might affect them with.

Constructively, there are several things an inspector can do to mitigate such circumstances. Part of the trouble can well be caused by not quite enough personal manufacturing knowledge, or a suitable conception of the commercial standards for the product his company sells, or sufficient detailed information concerning subsequent operations. Ignorance, of course, can always be overcome. Again, if the reversals are based mostly on disagreements over standards, specifications or tolerances, the inspector can start the ball rolling towards getting

official alterations investigated and effected. He might be the one to instigate a formal meeting of minds over disputed standards.

A Little Economics Provides a Better Perspective

People and companies are in business to make a profit. No business can exist long unless the income exceeds the outlay. Losses and expense in manufacturing can be built up in hundreds of different ways. If an inspector's interpretation of surface standards, for instance, unwittingly causes extra and unnecessary dressings of a grinding wheel, an unneeded loss has been incurred. For a company to buy even one wheel per year more than it needs is just one more drop of loss leaking from the bucket. Where an inspector fails to complete an inspection on time and causes a trucker to retrace his steps in order to pick up the delayed batch, a few more pennies' loss have disappeared down the drain.

In a sense, an inspector is constantly in a position to sabotage his company's profits. If he too constantly approves substandard work, then extra effort, motions, time and cost can build up at assembly or the inspector's carelessness may boomerang in the form of lost trade in the company's market from customer dissatisfaction over inferior merchandise.

On the other hand, he can build up unnecessary losses from being too strict and self righteous at his inspections. Always, somewhere in between, is the correct balance. No inspector probably ever achieves it, but he can assuredly try constantly for perfect decisions.

More than many others in the manufacturing areas, an inspector should acquire the broader thinking of top management and learn to realize the long range effect of his succession of immediate decisions on the company's profit and loss statement. Because inspection effort — the actual mechanics and techniques of inspections and gaging — are all too frequently necessarily picayunish and confining, it is all the more difficult for an inspector to "see the forest for the trees." When he is engrossed over distinguishing size differences of a tenth of a thousandth of an inch in parts, the climate is not conducive to remembering the effect of his measurements for good or bad on some product being shipped half way around the world. Dealing daily with only a dozen diverse humans running as many machines, plus perhaps wrangling with local

supervision and engineering, presents a very limited industrial horizon. The inspector lives usually in a very circumscribed valley and he needs regularly to climb the mountains, deliberately to get up on mental heights, and refresh his viewpoint by looking over (if only in imagination) the broader landscape of the business he is in.

Before he reaches a decision on a batch of obscure and apparently unimportant windshield wiper parts whose condition is marginal, for example, he should perhaps deliberately stop a second and think of a truck rumbling over a muddy mountain road in a driving rain at midnight before he reaches a decision to approve the batch. At the same time he should give a thought to one of his company's salesmen living in hotels and lower berths and cooling his heels in purchasing department reception rooms, beating his brains out trying to outwit some price cutting competition for the truck manufacturer's business, before deciding on a rejection. Too often the inspector broods only over the caustic personality of the production operator or the belief that the tight wad company should replace the obsolete monstrosity forming the parts with a new machine.

Inspection calls for knowledge, experience, judgment, vision, stability, consistency and horse sense, as well as an ability to expertly manipulate a set of gages. An inspector's conscientious attempt to develop such traits, in addition to manual dexterity and technical manufacturing knowledge, plus his growth in such factors as ingenuity, self-fueling energy, drive, friendliness and ability to influence people will soon work him out of a job — into a better one.

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